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RESEARCH MEMORANDUM

for the

Air Materiel Command, Army Air Forces

ALTITUDE COOLING INVESTIGATION OF THE R-2800-21 ENGINE

IN THE P-47G AIRPLANE

IV - ENGINE COOLING-AIR PRESSURE DISTRIBUTION

By Samuel J. Kaufman, Robert C. Staudt
and Michael F. Valerino

Aircraft Engine Research Laboratory
Cleveland, Ohio

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M. F. Valerino

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SUMMARY

A study of the data obtained in a flight investigation of an R-2800-21 engine in a P-47G airplane was made to determine the effect of the flight variables on the engine cooling-air pressure distribution. The investigation consisted of level flights at altitudes from 5000 to 35,000 feet for the normal range of engine and airplane operation.

The data showed that the average engine front pressures ranged from 0.73 to 0.82 of the impact pressure (velocity head). The average engine rear pressures ranged from 0.50 to 0.55 of the impact pressure for closed cowl flaps and from 0.10 to 0.20 for full-open cowl flaps.

In general, the highest front pressures were obtained at the bottom of the engine. The rear pressures for the rear-row cylinders were lower and the pressure drops correspondingly higher than for the front-row cylinders. The rear-pressure distribution was materially affected by cowl-flap position in that the differences between the rear pressures of the front-row and rear-row cylinders markedly increased as the cowl flaps were opened. For full-open cowl flaps, the pressure drops across the rear-row cylinders were in the order of 0.2 of the impact pressure greater than across the front-row cylinders.

Propeller speed and altitude had little effect on the cooling-air pressure distribution. Increase in angle of inclination of the thrust axis decreased the front pressures for the cylinders at the top of the engine and increased them for the cylinders at the bottom

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of the engine. As more auxiliary air was taken from the engine cowl, the front pressures and, to a lesser extent, the rear pressures for the cylinders at the bottom of the engine decreased.

No correlation existed between the cooling-air pressure-drop distribution and the cylinder-temperature distribution.

INTRODUCTION

At the request of the Air Materiel Command, Army Air Forces, an investigation was conducted at the NACA Cleveland laboratory to obtain information on the cooling characteristics of air-cooled engines at altitude conditions. As part of this investigation, tests were conducted on an R-2800-21 engine installed in a P-47G airplane at altitudes ranging from 5000 to 35,000 feet for the normal range of engine and airplane operation. An analysis of the cooling data obtained in the flight investigation to determine the effect of altitude cooling-air conditions on the over-all engine-cooling characteristics is presented in reference 1. During the flight investigation several methods of cooling cylinder 10, which ran abnormally hot at the medium-power and high-power conditions, were attempted as possible expedients for reducing the temperature spread between the hottest and average cylinders. The results of this phase of the investigation are reported in reference 2. The results of the flight investigation also showed that an extremely nonuniform temperature distribution existed among the 18 engine cylinders. An analysis of the effect of the engine and flight operating variables on the temperature distribution to determine which variable or group of variables was primarily responsible for the poor temperature distribution is presented in reference 3.

Inasmuch as a study of the temperature distribution would be incomplete without a similar study of the cooling-air pressure distribution, an investigation of the effect of the flight variables on the cooling-air pressure distribution was made and is reported. The study was made by selecting different series of flights in which, for each series, all of the variables except one were essentially constant and by plotting the cooling-air pressure patterns so as to indicate graphically the separate effect of each variable. The factors studied are cowl-flap position, propeller speed, quantity of auxiliary air flow, altitude, and angle of inclination of the thrust axis. The investigation includes an analysis of the circumferential pressure distribution ahead of and behind the engine cylinder heads, the radial pressure distribution ahead of and behind a representative cylinder, and the cooling-air pressure-drop distribution across the engine cylinder heads.

INSTALLATION AND INSTRUMENTATION

Power-plant installation. - The flight tests were conducted with an R-2800-21 engine installed in a P-47G airplane. The engine is an 18-cylinder, double-row radial, air-cooled engine with a normal rating of 1625 brake horsepower at 2550 rpm and a take-off rating of 2000 brake horsepower at 2700 rpm. The engine is equipped with a single-stage, single-speed, gear-driven supercharger (gear ratio, 7.6:1; impeller diameter, 11 in.); a General Electric Type C-1 turbosupercharger provides the auxiliary supercharging required for high-altitude operation. A Bendix-Stromberg PT-13G1 injection-type carburetor metered the fuel to the engine. The propeller is a four-blade Curtiss Electric controllable-pitch propeller (blade drawing No. 714-1C2-12), has a diameter of 12 feet 2 inches, and is fitted with shank cuffs. For the tests, the propeller reduction-gear case was replaced by a Pratt & Whitney torque nose having a propeller reduction-gear ratio of 2:1. A front- and side-view sketch of the power-plant installation is shown in figure 1.

The engine cowling is of standard NACA Type C and is fitted with eight adjustable cowl flaps, which extend around the upper half of the cowling perimeter. An additional fixed exit opening for the engine cooling air is provided around each side of the cowling down to the auxiliary air-supply scoop. The engine charge air and the cooling air for the intercooler, the oil coolers, and the exhaust-cooling shrouds are taken from the inside of the cowling below the engine through the auxiliary air-supply scoop.

Cooling-air pressure instrumentation. - The locations and designations of the pressure tubes used in the flight investigation are indicated in figures 2 and 3. Figure 2 shows the locations of the pressure tubes on an individual engine cylinder; figure 3 indicates the arrangement of cylinders and baffles on the engine and is presented to aid in showing the pressure-tube locations with respect to the engine as a whole. The cooling-air pressures in front of the engine were measured by shielded total-head tube H5 mounted in front of each cylinder head and by unshielded total-head tubes H1, H2, H3, and H4 installed between the cylinder fin tips and the baffle slightly behind the baffle entrance of each engine cylinder. The cooling-air pressures behind the engine were measured as follows: by open-end static tube P3 installed in the stagnation region behind the top head baffle of representative cylinders; by open-end static tubes P1 and P4 installed behind the curl of the intake-side baffles of each rear-row cylinder at right angles to the general direction of the cooling-air flow; and by closed-end static tubes P5 and P6 mounted on rakes downstream of each engine cylinder. The method used to lead the pressure tubes out of the cooling-air passages and around the outside

of the sealing ring to the bottom and sides of the engine is shown in figure 4. This pressure-tube installation was chosen in order to minimize the interference of the tubes with the cooling-air flow across the engine.

The cooling-air pressures were led to pressure selector valves which, in turn, were connected to NACA film-recording multiple manometers. The precision of the pressure readings was estimated to be within ± 2 percent; the time required for recording a complete set of pressures was approximately 2 minutes.

General instrumentation. - The free-stream impact and static pressures were obtained from measurements with a shielded total-head tube and a swiveling static tube installed on a streamline boom attached to the right wing. The pressures were recorded by standard NACA recorders and were used to determine the airplane speed and pressure altitude.

The free-air temperature was measured by a flight-calibrated resistance-bulb thermometer installed under the right wing. The engine speed was recorded on an NACA flight recorder by a counter and timer combination; the engine power was calculated from the recorded engine speed and the torque-nose indication, which was read by the pilot. An inclinometer was installed to give continuous readings of inclination of the thrust axis. NACA control-position recorders were used to record mixture-control setting, cowl-flap position, and intercooler-shutter position.

METHODS

The method of analysis of the cooling-air pressure distribution used in the investigation of the R-2800-21 engine installed in a P-47G airplane was as follows:

General flight program. - The flight investigation was conducted at altitudes of 5000, 10,000, 25,000, 30,000, and 35,000 feet; a few flights were also made at intermediate altitudes. The three main controllable variables during each flight at a given altitude were engine power, propeller speed, and cooling-air pressure drop; in general, during each constant-altitude flight one of these three variables was independently varied while the other two were maintained constant.

The engine power was controlled with the carburetor throttle and, at the high altitudes, also with the turbosupercharger waste gate. The mixture control was set in the automatic-rich position and the fuel-air ratio was allowed to vary according to the carburetor characteristics.

The engine speed was controlled with the propeller governor and the cooling-air pressure drop was controlled by means of the cowl-flap deflection and the airplane velocity, which differed with the landing-gear position.

Analysis of engine cooling-air pressure distribution. - The flight-cooling variables involved in the study of the cooling-air pressure distribution are cowl-flap position, propeller speed, quantity of auxiliary air taken from the cowl, altitude, and angle of inclination of the thrust axis. The study includes an investigation of the circumferential pressure distribution ahead of and behind the engine cylinder heads, the radial pressure distribution ahead of and behind a representative cylinder, and the cooling-air pressure-drop distribution across the engine cylinder heads. In order to separate the effect of each individual flight-cooling variable, various series of flight runs were chosen in which, for each series, all but the particular flight variable under investigation were held substantially constant.

The pressure values are presented in terms of p/q_c , which represents the ratio of the pressure above free-stream static pressure at each point ahead of or behind the engine p to the measured free-stream impact pressure (velocity head) q_c . The p/q_c ratio is plotted against cylinder number on polar coordinate paper for the study of the circumferential pressure distribution and is plotted against the radial distance from the base to the top of the cylinder for the study of the radial pressure distribution. The circumferential pressure-drop distribution is presented as the ratio of pressure drop to free-stream impact pressure $\Delta p/q_c$.

A front-view sketch of the engine showing the 18 cylinders is included at the center of the polar coordinate plots to aid in quick identification of the various positions in front of or behind the cylinders. The individual cylinders are numbered in conformity with present practice, the even-numbered cylinders are in the front row and the odd-numbered cylinders in the rear row.

Pressure tubes H5 and P5 were used for the circumferential and pressure-drop distribution patterns. Other pressure tubes responded in a similar manner to changes in operating variables and could also have been used. Pressure tubes H1, H3, H4, and H5 were used for the study of the radial pressure distribution ahead of a representative cylinder (cylinder 9); pressure tubes P3, P5, and P6 were used for a similar study of distribution behind this cylinder.

For convenience a list of the values of the principal variables in each flight run used for the subject analysis is presented in table I.

RESULTS AND DISCUSSION

The results of the study to determine the effect of the flight-cooling variables on the cooling-air pressure distribution of the R-2800-21 engine as installed in the P-47G airplane are graphically presented in figures 5 to 11. Although each figure strictly applies for a specific set of conditions (table I), the trends indicated have been found from a more exhaustive study, not presented, to be representative of other conditions.

General results. - For the large range of flight conditions investigated, the average pressures ahead of the cylinders (front pressures) ranged from 0.73 to 0.82 (p/q_c ratio). For any given flight conditions, the highest front pressures were obtained at the bottom of the engine. The average rear pressures ranged from 0.50 to 0.55 for the closed-flap position and from 0.10 to 0.20 for the full-open-flap position. Generally, the rear pressures for the rear-row cylinders were lower than the rear pressures for the front-row cylinders. Consistent with this result, the pressure drops (and thus the cooling-air flow) across the rear-row cylinders were greater than across the front-row cylinders.

Reproducibility. - An indication of the reproducibility of the test data is presented in figure 5, which gives a comparison of the pressure patterns for two nearly identical flight runs, one conducted near the beginning and the other at the end of the flight investigation. Good agreement between the pressure distributions for the two runs is shown; the largest discrepancies were obtained for the circumferential pressure-drop patterns, which essentially cumulate the small differences obtained in both the front- and rear-circumferential pressure patterns.

Effect of cowl-flap position. - The cooling-air pressure distribution as affected by the movement of the eight adjustable cowl flaps (extending around the entire upper half of the cowl perimeter) from the full-open position of 17.5° to the closed position of 7.0° is shown in the data plots of figure 6. At the closed position, the flaps are flush with the engine cowl but still provide an opening for the flow of cooling air past the flaps into the free-air stream. In order to maintain constant flight-cooling variables, the engine power, which in itself has no effect on the cooling-air pressures (propeller conditions were later shown to have no discernable effects) was allowed to vary for these runs.

Figure 6(a) shows that the front-pressure patterns, although slightly scattered, have no particular trend with cowl-flap position. The average front pressure with full-open and closed flaps was $0.73 q_c$ and $0.73 q_c$, respectively.

The cooling-air pressure (fig. 6(b)) behind the engine (rear pressure) was greatly affected by cowl-flap position, the average rear pressure changing from approximately $0.5 q_c$ for closed-flap position to $0.2 q_c$ for the full-open position. In general, the pressures behind the rear-row cylinders were lower than those directly behind the front-row cylinders. As the cowl flaps were opened to increase the cooling-air flow across the engine, the differences between the rear pressures of the front-row and the rear-row cylinders markedly increased; extremely jagged patterns of rear pressure were thus obtained for the half-open and full-open flap positions.

The flow path of the cooling air across the front-row and rear-row cylinders of the engine is indicated in figure 3, which shows that the cooling air leaving the front-row cylinders must flow through restricted spaces between the rear-row cylinders to reach the rear engine compartment. The pressure differences between the rears of the front-row and rear-row cylinders may possibly be explained as the result of the additional pressure losses sustained by the cooling air of the front-row cylinders in flowing through the restricted spaces to the rear engine compartment (where the rear pressures of the rear-row cylinders were measured). A similar effect was not obtained, however, for the front pressures of the front-row and rear-row cylinders.

The rear static pressures were higher at the bottom of the engine than at the top, as would be expected from the fact that the cowl flaps are at the top and a pressure loss was sustained by the cooling air in flowing from the bottom of the engine to the cowl-flap exit. The difference between the bottom and top pressures increased as the cowl flaps were opened.

The general shape of the radial pressure distribution (fig. 6(c)) is altered only slightly by change in cowl-flap position. Front pressure increased with radial distance from the base to the top of the cylinder and, in addition, the rear pressures were lower behind the cylinder head than behind the barrel; consistent with these results, the largest pressure drop across the cylinder was obtained near the top of the cylinder head.

The pressure-drop distribution shown in figure 6(d) reflects the changes in the circumferential distribution in front of and behind the cylinder heads. The general shape of the pressure-drop patterns is similar for the different cowl-flap openings; for the full-open position, the pressure drop across a rear-row cylinder is approximately $0.2 q_c$ higher than the drop across an adjacent front-row cylinder.

Effect of propeller speed. - Figure 7 presents the cooling-air pressure distributions for propeller speeds from 960 to 1350 rpm. Varying the propeller speed and, consequently, the blade angle had no substantial effect on the cooling-air pressure distribution for the range of speeds tested, although it may have affected the turbulence of the cooling air and therefore varied its cooling effectiveness.

Effect of auxiliary air flow. - The charge air for the engine and the cooling air for the intercooler, the oil coolers, and the exhaust-cooling shrouds enter the cowl with the engine cooling air and are diverted to the auxiliary air scoop located beneath the engine (fig. 1). In order to determine whether variations in the quantity of auxiliary air taken from the engine cowl affect the engine cooling-air pressure distribution, a study was made of the cooling-air pressure distributions obtained for variable intercooler-shutter position. Estimates indicate that at the full-open intercooler-shutter position, the intercooler cooling air constitutes about 20 percent of the total air that enters the engine cowl. The results of this study are presented in figure 8, which shows that only the cylinders at the bottom of the engine (cylinders 8 to 12) are affected by changes in intercooler-shutter position. As the shutters were moved from closed to full-open position (in which case the quantity of air diverted to the auxiliary air duct was increased), the front pressure for the bottom cylinders 8 to 12 was decreased about $0.1 q_c$ (fig. 8(a)). The rear pressures for cylinders 8 to 12 were also reduced (fig. 8(b)), although to a lesser extent than the front pressures, which resulted in a decreased pressure drop across the bottom cylinders (fig. 8(d)). A possible remedy for the foregoing condition would be to extend the dividing plate to the front edge of the cowl, and thus allow the accessory air to be drawn from the free-air stream rather than from the engine cooling-air stream. Figure 8(c) shows that the shape of the radial distribution pattern is essentially unaffected by the changes in intercooler-shutter position.

Effect of altitude. - The cooling-air pressure distribution curves for a range of altitude from approximately 5000 to 35,000 feet at constant inclination of the thrust axis are presented in figure 9. This figure shows a fairly substantial amount of scatter but no apparent trend with altitude. These plots indicate that the circumferential, radial, and pressure-drop distributions were substantially unaffected by changes in altitude.

Effect of inclination of thrust axis. - Operational limitations of the P-47G airplane made it impossible to obtain variation of inclination of thrust axis in level flight without an accompanying variation of airplane velocity and thus of engine cooling-air impact pressure. Because

impact pressure should theoretically have little effect on the cooling-air distribution, however, the combined effect of inclination of thrust axis and of impact pressure obtained in the tests is assumed to represent principally the effect of inclination of the thrust axis.

The variation in angle of inclination of the thrust axis was accomplished by two methods, namely, (1) through the introduction of parasitic drag by lowering the landing gear, and (2) through changes in engine power. The effect of angle of inclination of the thrust axis on the cooling-air pressure distribution is presented in figures 10 and 11 for the two methods of changing inclination of the thrust axis. Figure 10(a) shows that as the angle of inclination of the thrust axis was increased from 1.5° to 4.0° the average increase in front pressures for cylinders 10 to 16 was $0.1 q_c$; whereas, elsewhere on the engine the average decrease in pressures was about $0.05 q_c$. The static-pressure distribution behind the engine reflected similar trends with respect to inclination of the thrust axis, although to a lesser degree (fig. 10(b)). Figure 10(c) shows that the radial distribution was unaffected by changes in angle of inclination. Because of the relatively small change in rear pressures with inclination of the thrust axis, the pressure-drop distribution (fig. 10(d)) was similar to the front-pressure distribution. A distinct cross-over of the patterns was noted between cylinders 9 and 11 and cylinders 16 and 17. Inspection of figure 11, which was presented for variable power conditions, shows that the trends in pressure patterns were similar to those shown in figure 10; in general, an increase in angle of inclination of the thrust axis resulted in higher front pressures and correspondingly higher pressure drops at the bottom of the engine at the sacrifice of lower front pressures (and thus lower pressure drops) for the top of the engine.

Comparison of pressure-drop and temperature distributions. - A comparison of the pressure-drop patterns presented herein with the temperature patterns presented in reference 3 shows that no correlation existed between the cooling-air pressure-drop distribution and the cylinder-temperature distribution. Thus, the dispersion in cooling-air distribution is not the principal factor that produces the dispersion in the cylinder-temperature distribution.

SUMMARY OF RESULTS

A study of the results of an investigation conducted on an R-2800-21 engine installed in a P-47G airplane to determine the effect of the flight variables on the engine cooling-air pressure distribution showed that:

1. For the large range of flight conditions tested, the average engine front pressures ranged from 0.73 to 0.82 of the impact pressure (velocity head). The average engine rear pressures ranged from 0.50 to 0.55 of the impact pressure for closed cowl flaps and from 0.10 to 0.20 for full-open cowl flaps.

2. In general, the highest front pressures were obtained at the bottom of the engine. The rear pressures for the rear-row cylinders were lower and the pressure drops correspondingly higher than for the front-row cylinders.

3. The rear-pressure distribution and thus the pressure-drop distribution were materially affected by cowl-flap position in that the differences between both the rear pressures and pressure drops of the front-row and rear-row cylinders markedly increased as the cowl flaps were opened. For the full-open flap position, the average pressure drops across the rear-row cylinders were approximately 0.2 of the impact pressure greater than across the front-row cylinders. The rear static pressures were higher at the bottom than at the top of the engine because the cowl flaps are located at the top and a pressure loss was sustained by the cooling air in flowing from the bottom to the top of the engine. The difference increased as the cowl flaps were opened.

4. Propeller speed and altitude at constant inclination of the thrust axis had no appreciable effect on the cooling-air pressure distribution in front of or behind the engine.

5. As more auxiliary air was taken from the engine cowling, the front pressures and, to a lesser extent, the rear pressures for the cylinders at the bottom of the engine were decreased.

6. Increase in angle of inclination of the thrust axis decreased the front pressures for the cylinders at the top of the engine and increased the front pressures for the cylinders at the bottom of the engine. The rear pressures were affected in a similar manner but to a lesser extent.

7. The cooling-air pressure-drop distribution across the engine did not account for the cylinder-temperature distribution obtained.

Aircraft Engine Research Laboratory,
National Advisory Committee for Aeronautics,
Cleveland, Ohio.

Samuel J. Kaufman

Samuel J. Kaufman,
Mechanical Engineer.

Robert C. Staudt,
Aeronautical Engineer.

Michael F. Valerino

Michael F. Valerino,
Aeronautical Engineer.

Approved:

E. J. Manganiello

E. J. Manganiello,
Mechanical Engineer.

Benjamin Pinkel

Benjamin Pinkel,
Physicist.

L. A. Rodert

Lewis A. Rodert,
Aeronautical Engineer.

Abe Silverstein

Abe Silverstein,
Aeronautical Engineer.

vab

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- (a) Circumferential distribution of total-head pressure in front of cylinders, H5.
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Figure 9. - Effect of altitude at constant inclination of the thrust axis on cooling-air pressure distribution.

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- (d) Circumferential distribution of pressure drop across cylinder heads, (H5 - P5).

Figure 10. - Effect of angle of inclination of airplane thrust axis at constant engine power on cooling-air pressure distribution.

- (a) Circumferential distribution of total-head pressure in front of cylinders, H5.
- (b) Circumferential distribution of static pressure at rear of cylinders, P5.
- (c) Radial distribution, cylinder 9.
- (d) Circumferential distribution of pressure drop across cylinder heads, (H5 - P5).

Figure 11. - Effect of angle of inclination of airplane thrust axis at variable engine power on cooling-air pressure distribution.

- (a) Circumferential distribution of total-head pressure in front of cylinders, H5.
- (b) Circumferential distribution of static pressure at rear of cylinders, P5.
- (c) Radial distribution, cylinder 9.
- (d) Circumferential distribution of pressure drop across cylinder heads, (H5 - P5).

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TABLE I -- SUMMARY

Condition	Flight	Run	Altitude (ft)	Propeller speed (rpm)	Mani- fold pres- sure (in. Hg abso- lute)
Reproducibility	18	2	4,800	1290	36.2
	64	3	5,050	1285	37.7
Variable cowl- flap position	17	1	5,050	1295	28.2
	19	^c 5	5,220	1290	42.0
	14	3	5,200	1290	25.5
Variable propeller speed	47	1	10,610	960	35.7
	47	2	10,640	1010	33.1
	47	3	10,610	1100	29.7
	47	4	10,600	1205	27.9
	47	5	10,610	1285	26.7
	47	6	10,610	1350	26.0
Variable inter- cooler-shutter position	37	1	10,370	1285	39.0
	37	2	10,420	1285	40.1
	37	3	10,430	1285	39.9
	37	5	10,410	1295	40.3
Variable altitude	18	^c 4	4,500	1285	36.9
	13	3	9,340	1275	24.0
	45	1	15,080	935	29.3
	42	3	24,450	1300	27.4
	46	3	34,870	1285	34.6
Variable angle of inclination at con- stant engine power	30	3	29,680	1275	41.8
	30	^c 4	29,390	1270	40.8
Variable angle of inclination at var- iable engine power	14	^c 4	5,090	1290	25.7
	17	3	5,070	1300	28.3
	19	3	5,230	1285	42.2

^aCowl-flap positionAngle
(deg)

Full open

17.5

One-half open

12.3

Closed

7.0

^bIntercooler-shutter position Approximate opening
(sq in.)

Closed

0

One-fourth open

25

Neutral (one-half open)

70

Open

150

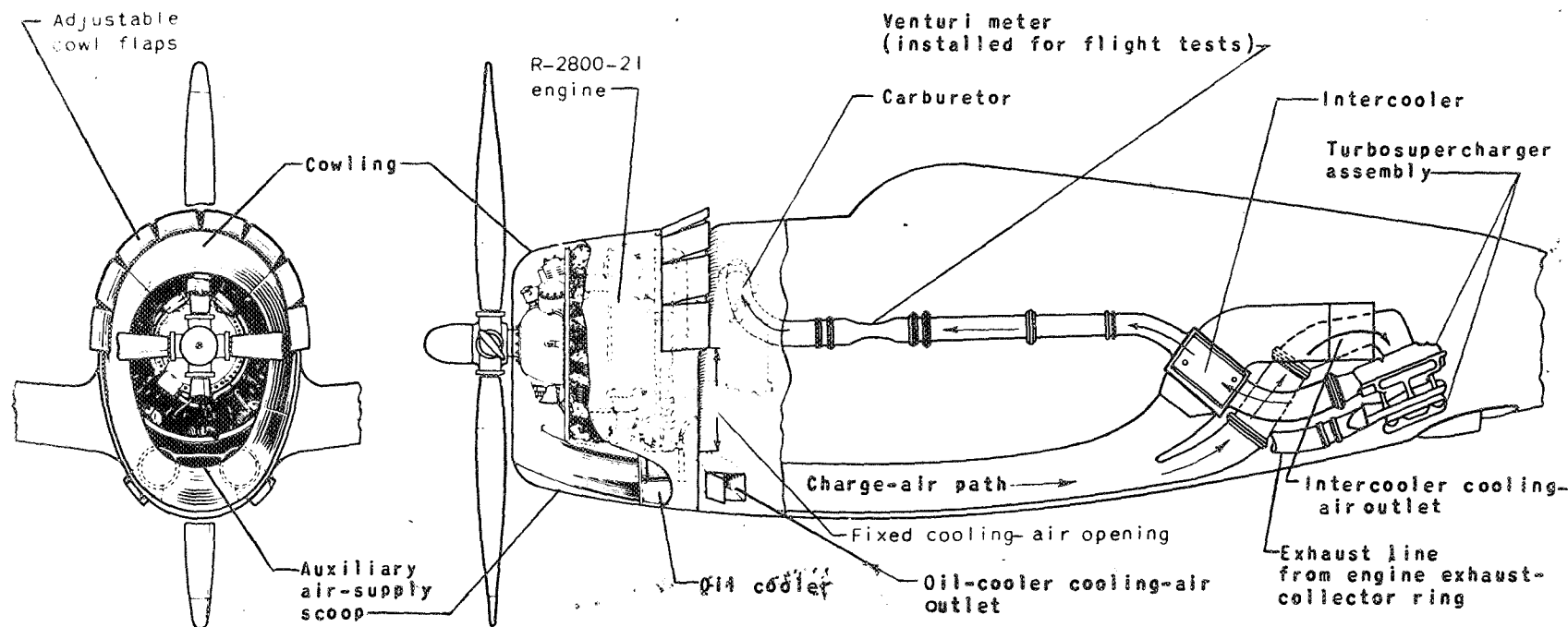
^cLanding gear down.

OF FLIGHT CONDITIONS

Engine power (bhp)	Cowl-flap position (a)	Impact pressure (in. water)	Angle of inclination of thrust axis (deg)	Intercooler-shutter position (b)	Figure
1310 1380	One-half open One-half open	36.7 34.7	2.5	Neutral Neutral	5
970 1560 820	Full open One-half open Closed	24.5 22.6 23.3	2.8 2.1 2.9	Neutral Neutral Neutral	6
1130 1100 1020 1000 970 930	One-half open One-half open One-half open One-half open One-half open One-half open	29.5 28.6 27.3 27.0 26.2 24.3	2.2 2.6 2.8 2.7 2.8 3.1	Neutral Neutral Neutral Neutral Neutral Neutral	7
1430 1470 1470 1470	One-half open One-half open One-half open One-half open	36.2 35.2 37.7 37.8	2.3 2.0 1.8 1.9	Closed Open One-fourth open Neutral	8
1380 790 850 1000 1200	Closed Closed Closed Closed Closed	22.0 21.9 20.9 21.7 20.9	3.1 4.2 3.6 3.8	Neutral Neutral Neutral Neutral Neutral	9
1270 1280	Closed Closed	31.4 15.8	1.5 4.0	Neutral Neutral	10
810 970 1560	Closed Closed Closed	13.0 28.6 43.2	6.0 1.9 .8	Neutral Neutral Neutral	11

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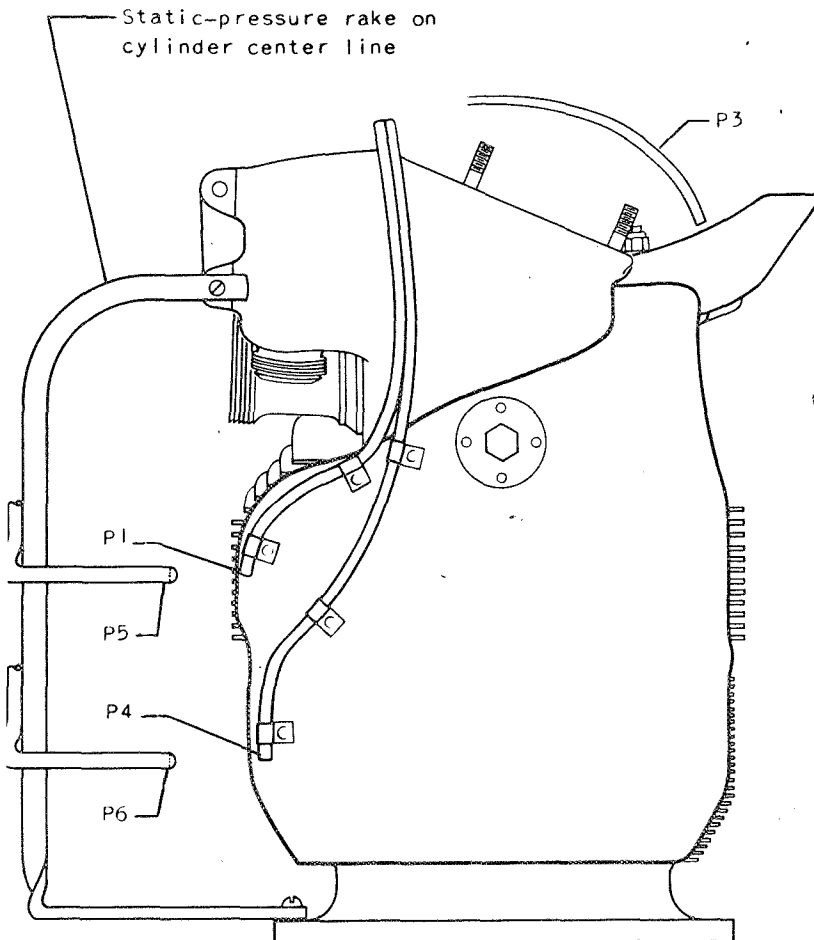
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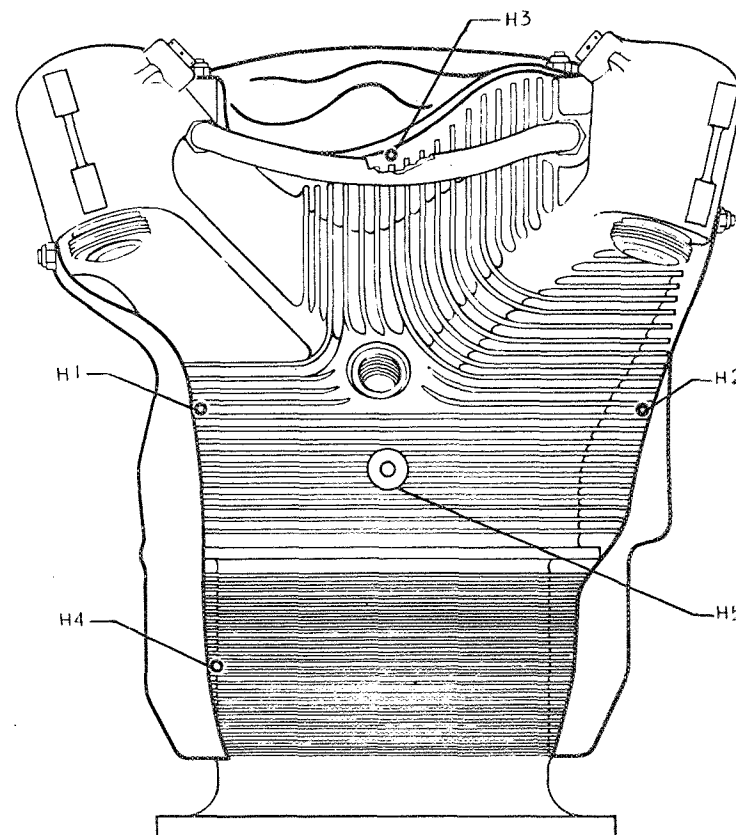
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Figure 1. - Power-plant installation in P-47G airplane.

Fig. 1



Intake-side view of rear-row cylinder showing static-pressure tube locations



Front view of front-row cylinder showing total-head pressure tube locations

Figure 2. - Cylinder total-head and static-pressure tube locations.

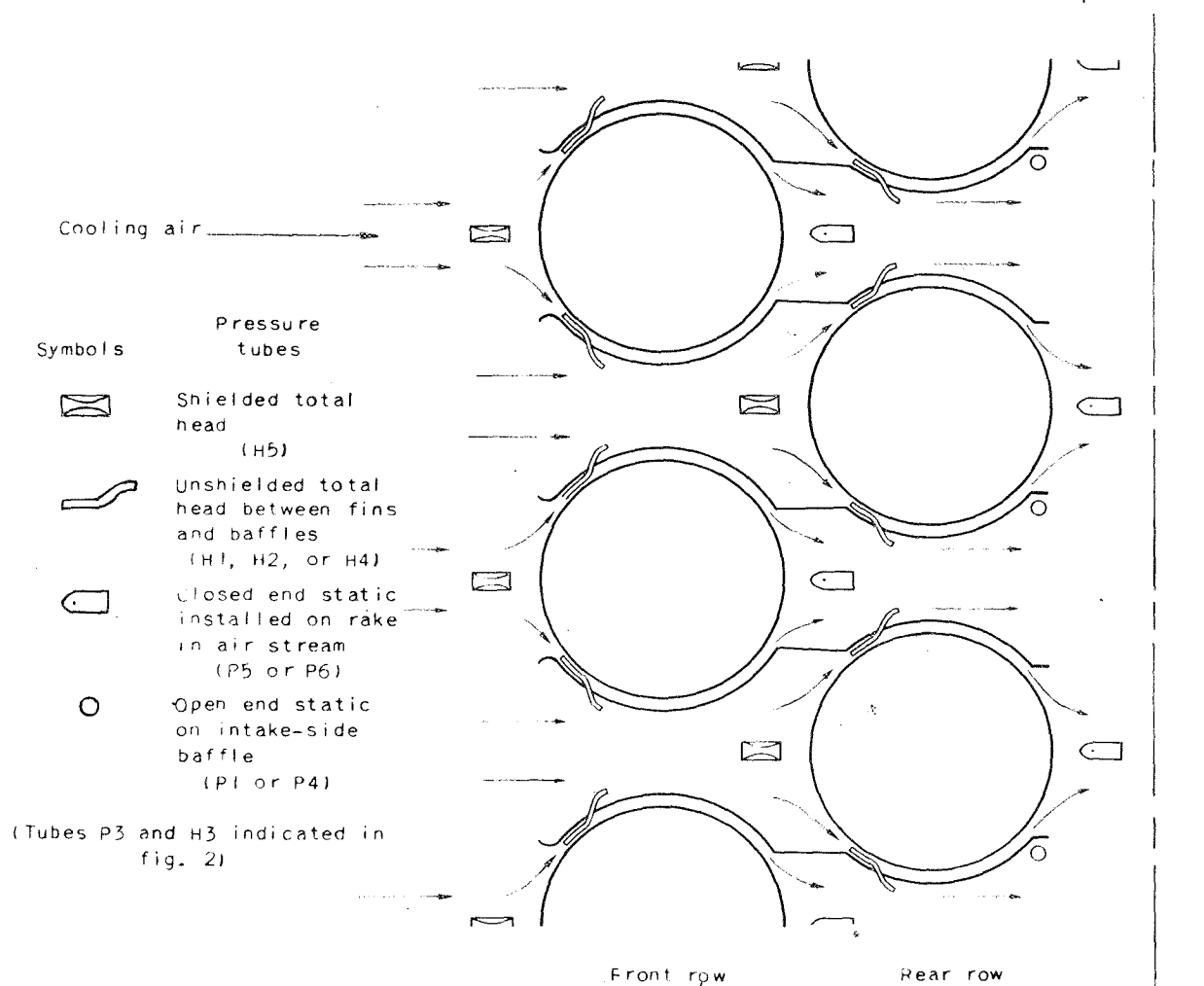
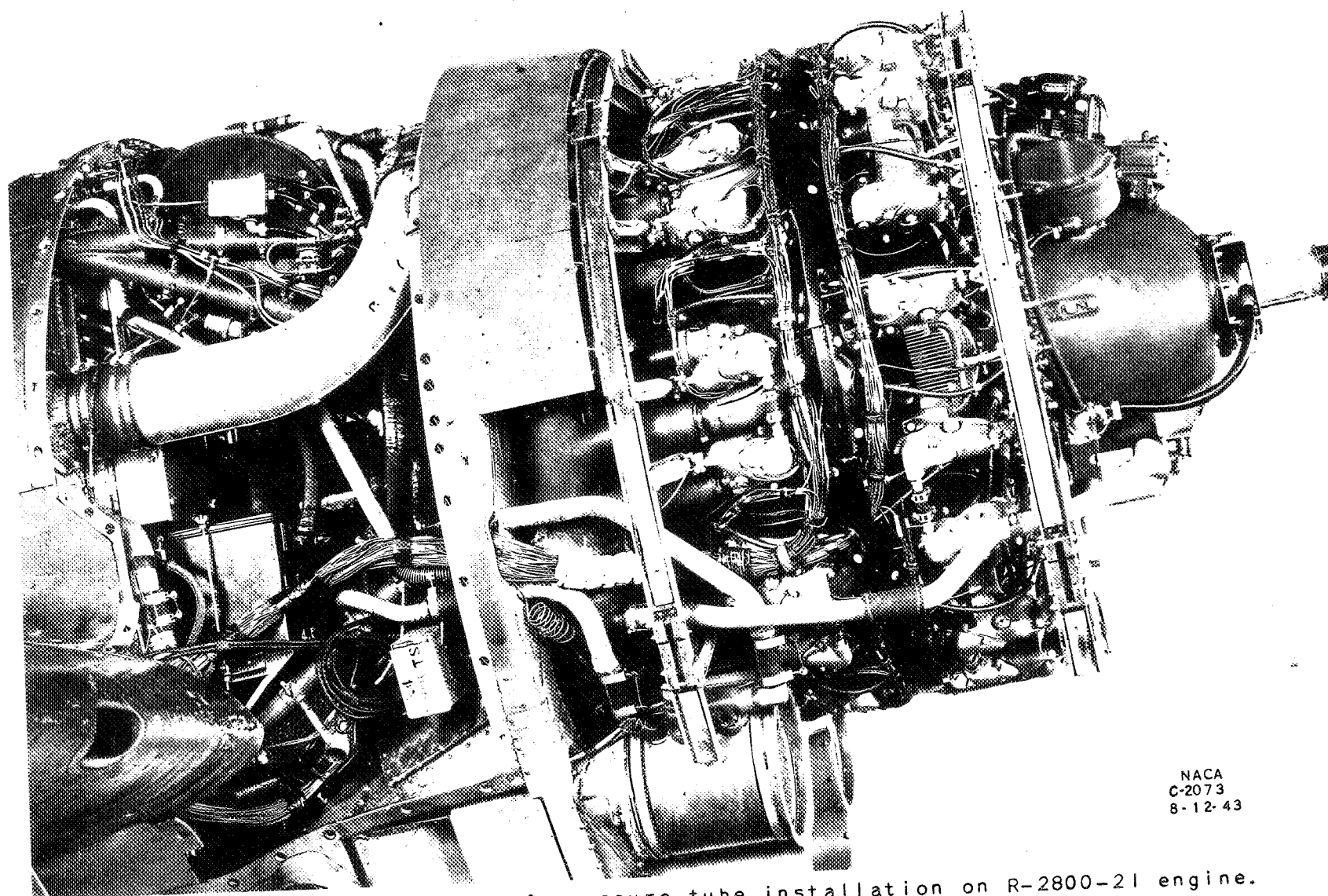
NATIONAL ADVISORY
COMMITTEE FOR AERONAUTICSPlane of
rear engine
compartment

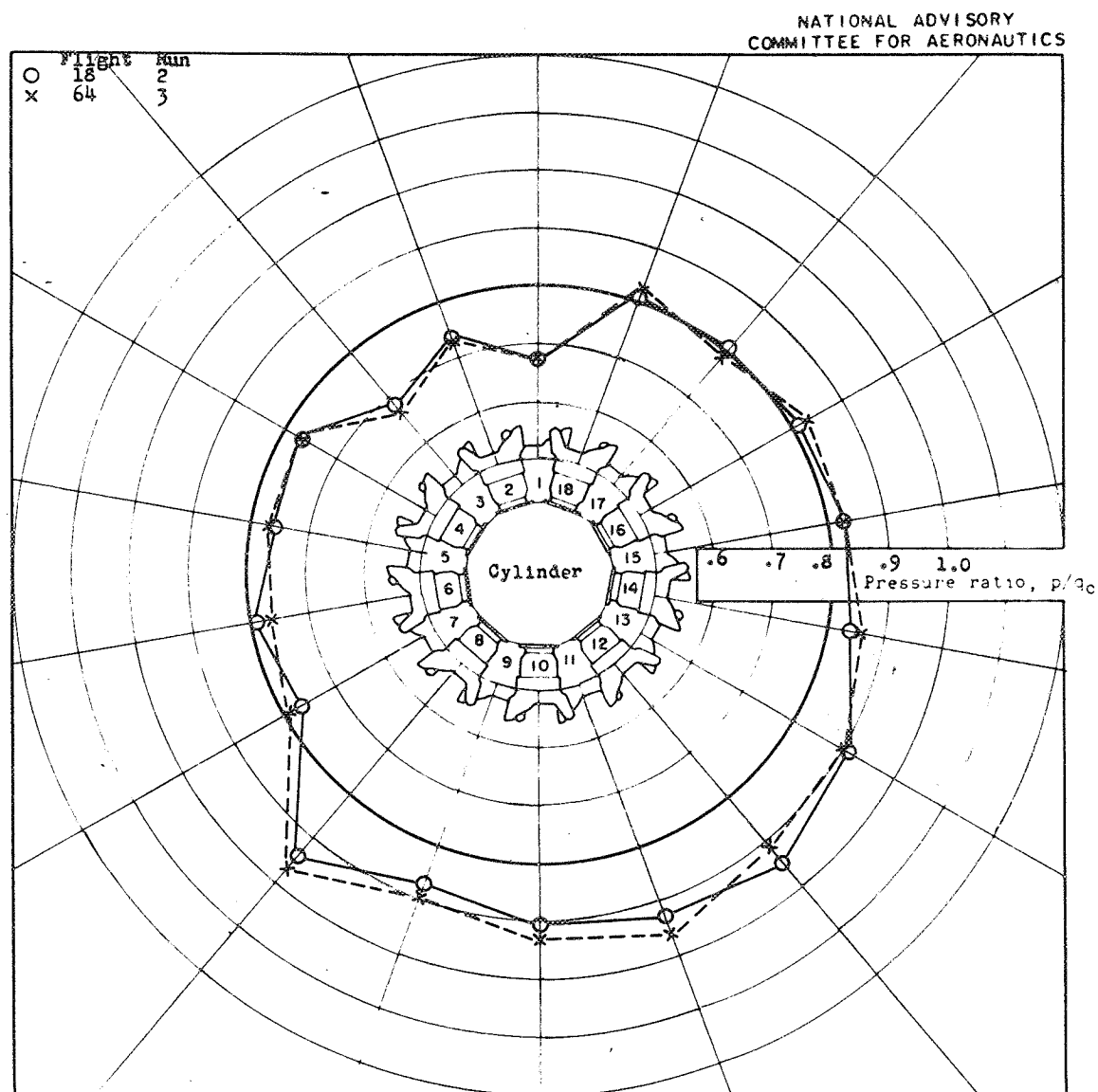
Figure 3. - Schematic diagram showing cylinder arrangement (from the side) on R-2800-21 engine and position of pressure tubes with respect to cylinder and baffle.



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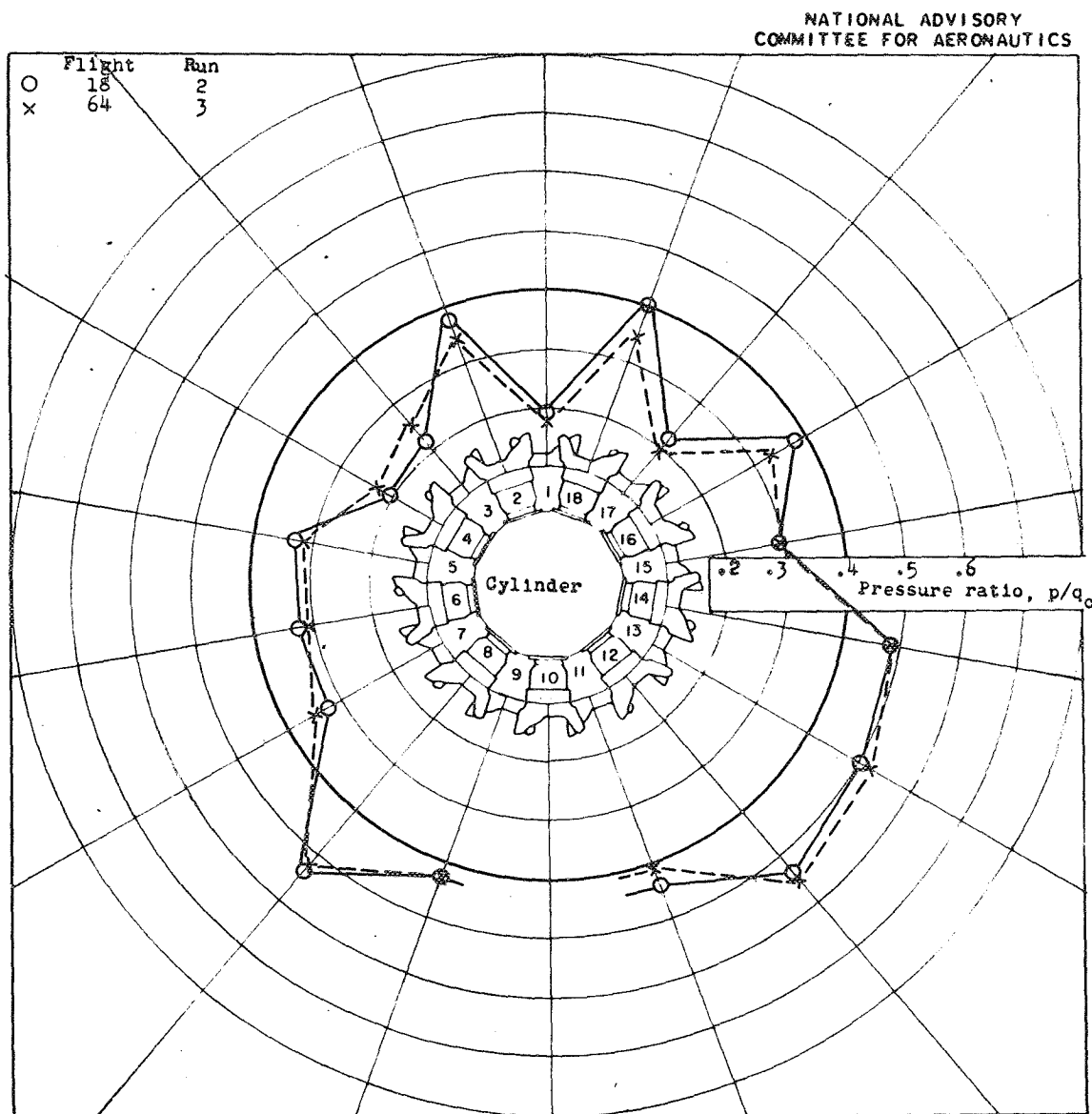
Fig. 4

Figure 4. - General view of pressure-tube installation on R-2800-21 engine.



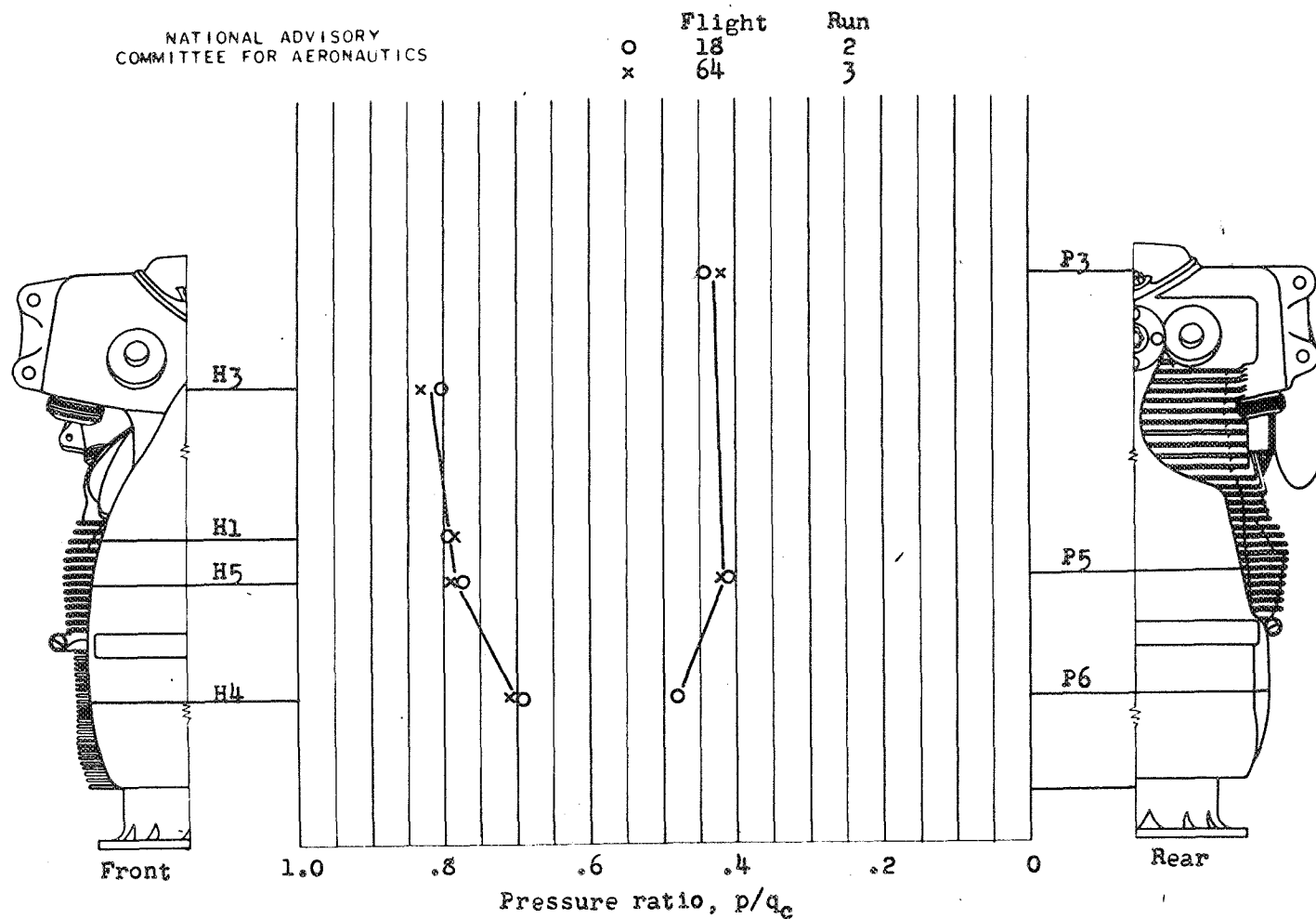
(a) Circumferential distribution of total-head pressure in front of cylinders, H5.

Figure 5. - Reproducibility of cooling-air pressure distribution patterns for two nearly identical flight runs.



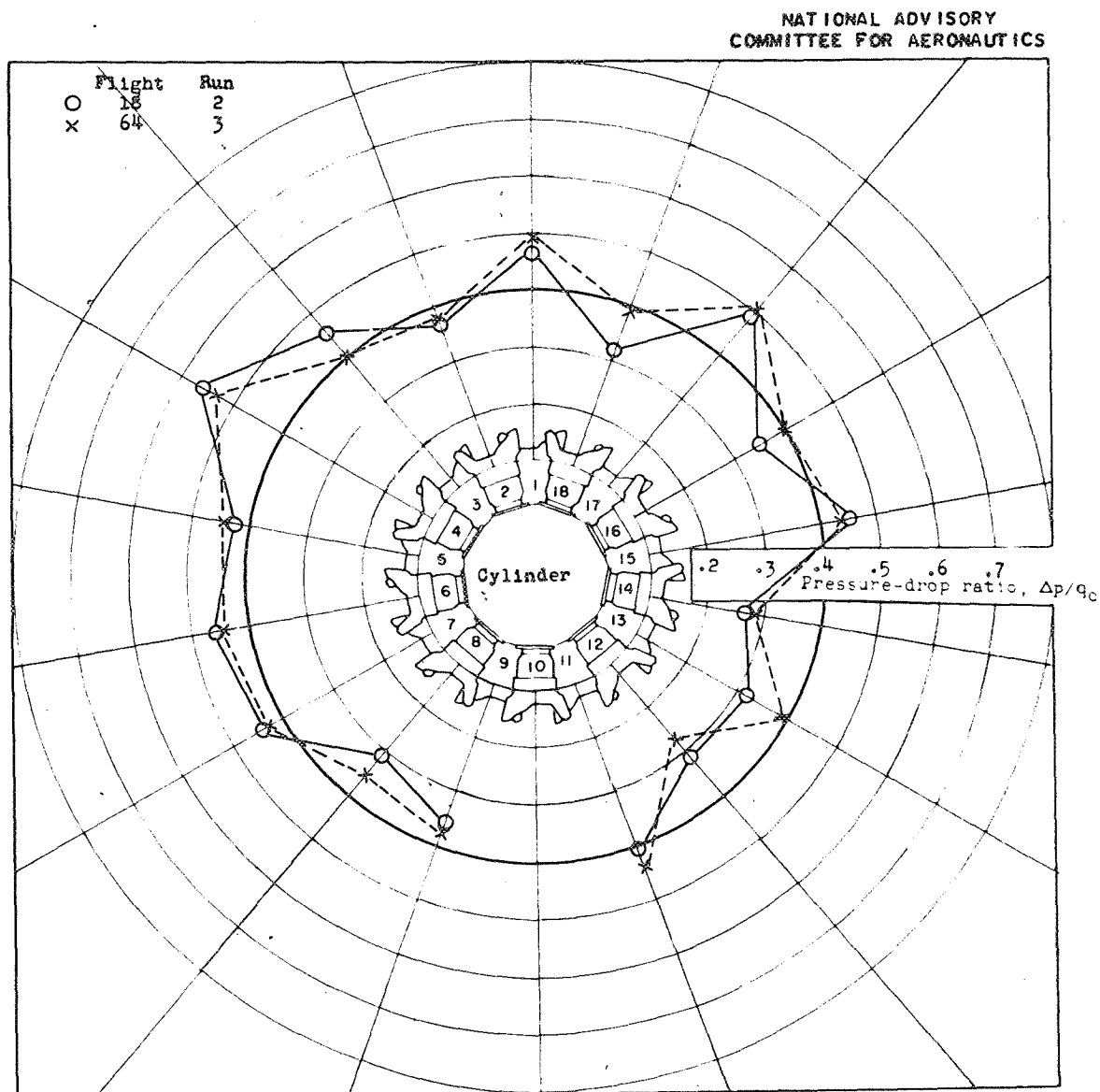
(b) Circumferential distribution of static pressure at rear of cylinders, P5.

Figure 5. - Continued. Reproducibility of cooling-air pressure distribution patterns for two nearly identical flight runs.



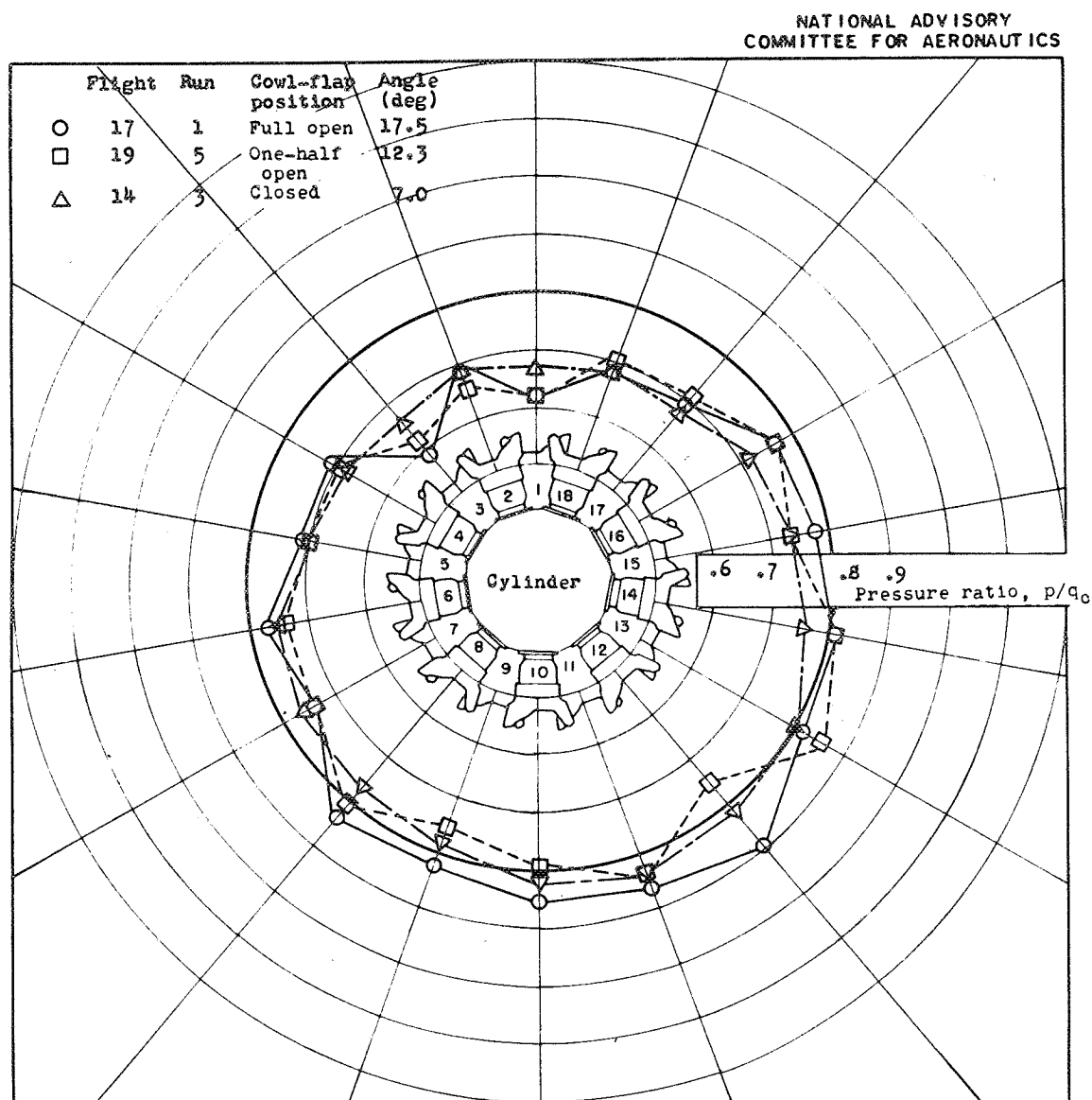
(c) Radial distribution, cylinder 9.

Figure 5. - Continued. Reproducibility of cooling-air pressure distribution patterns for two nearly identical flight runs.

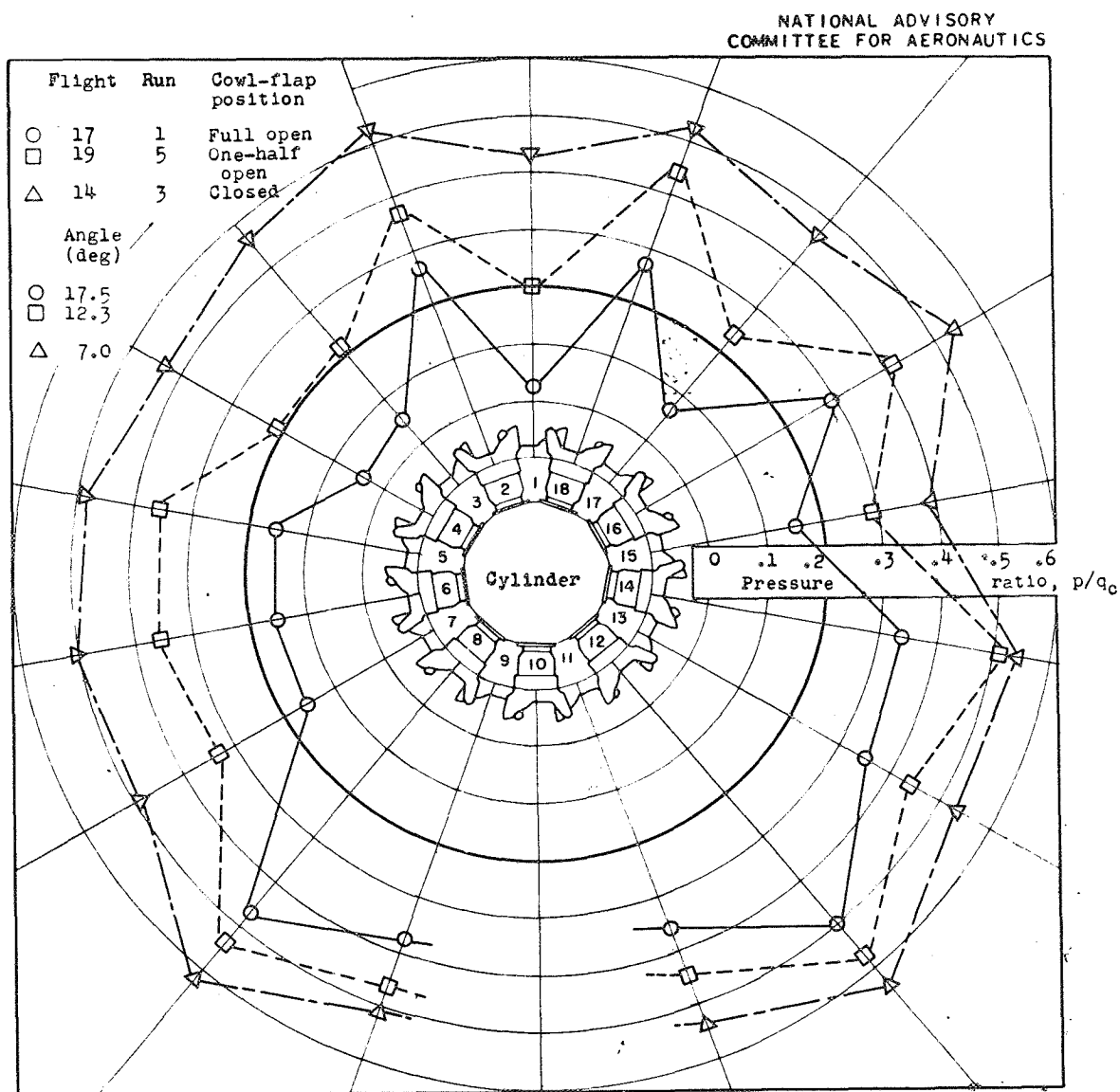


(d) Circumferential distribution of pressure drop across cylinder heads, (H5 - P5).

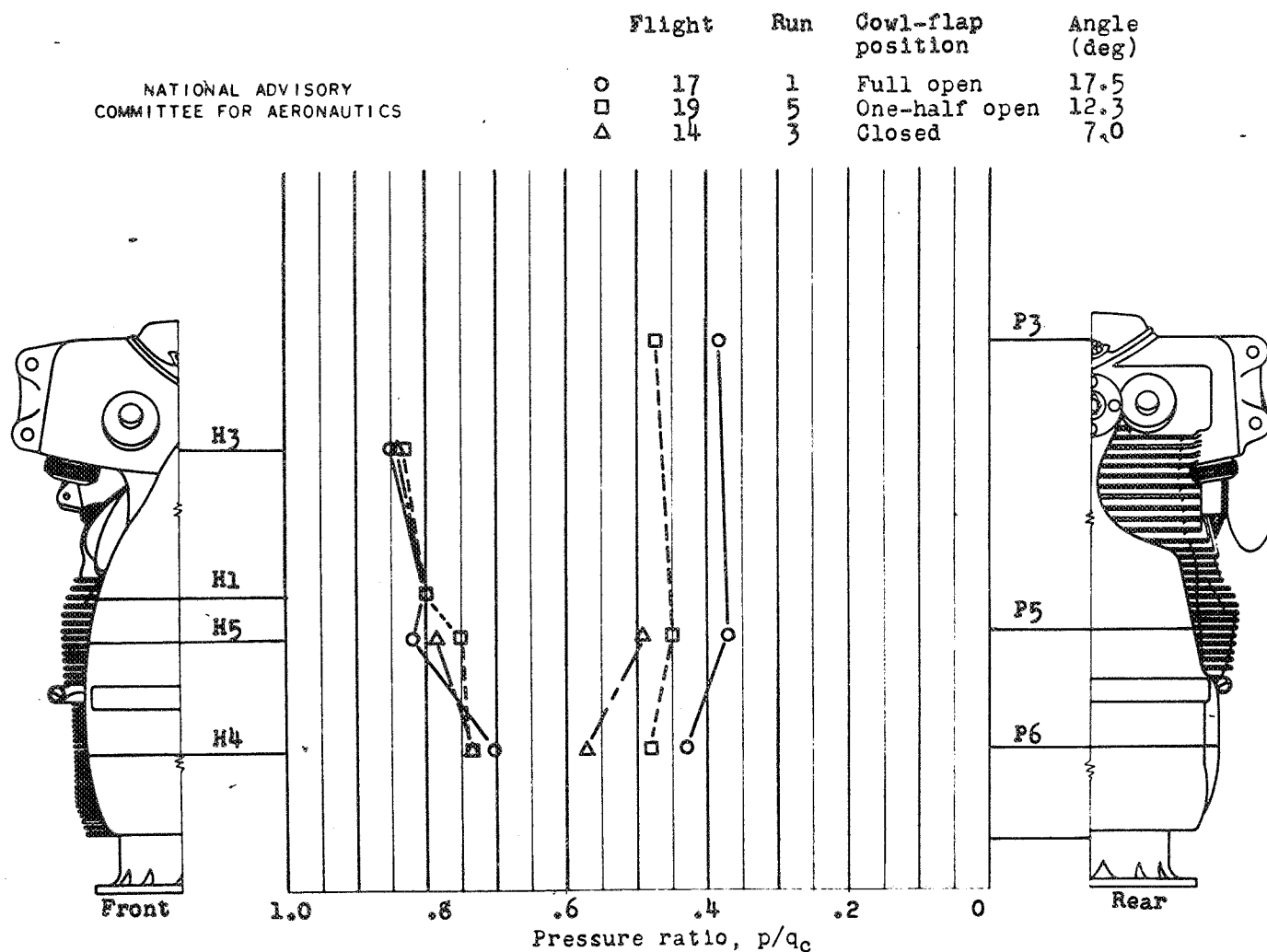
Figure 5. - Concluded. Reproducibility of cooling-air pressure distribution patterns for two nearly identical flight runs.



(a) Circumferential distribution of total-head pressure in front of cylinders, H5.
Figure 6. - Effect of cowl-flap position on cooling-air pressure distribution.

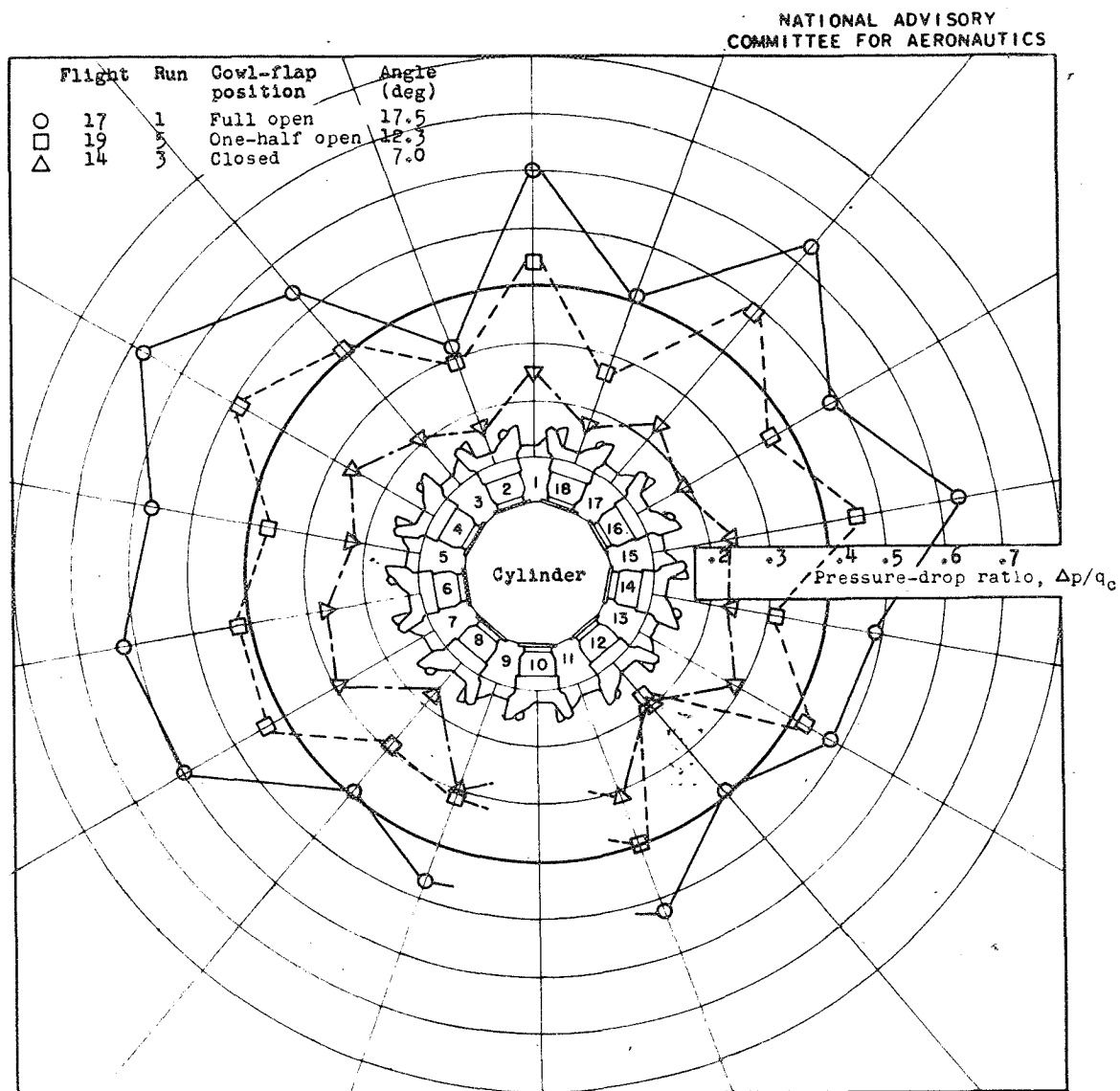


(b) Circumferential distribution of static pressure at rear of cylinders, P_5 .
Figure 6. - Continued. Effect of cowl-flap position on cooling-air pressure distribution.



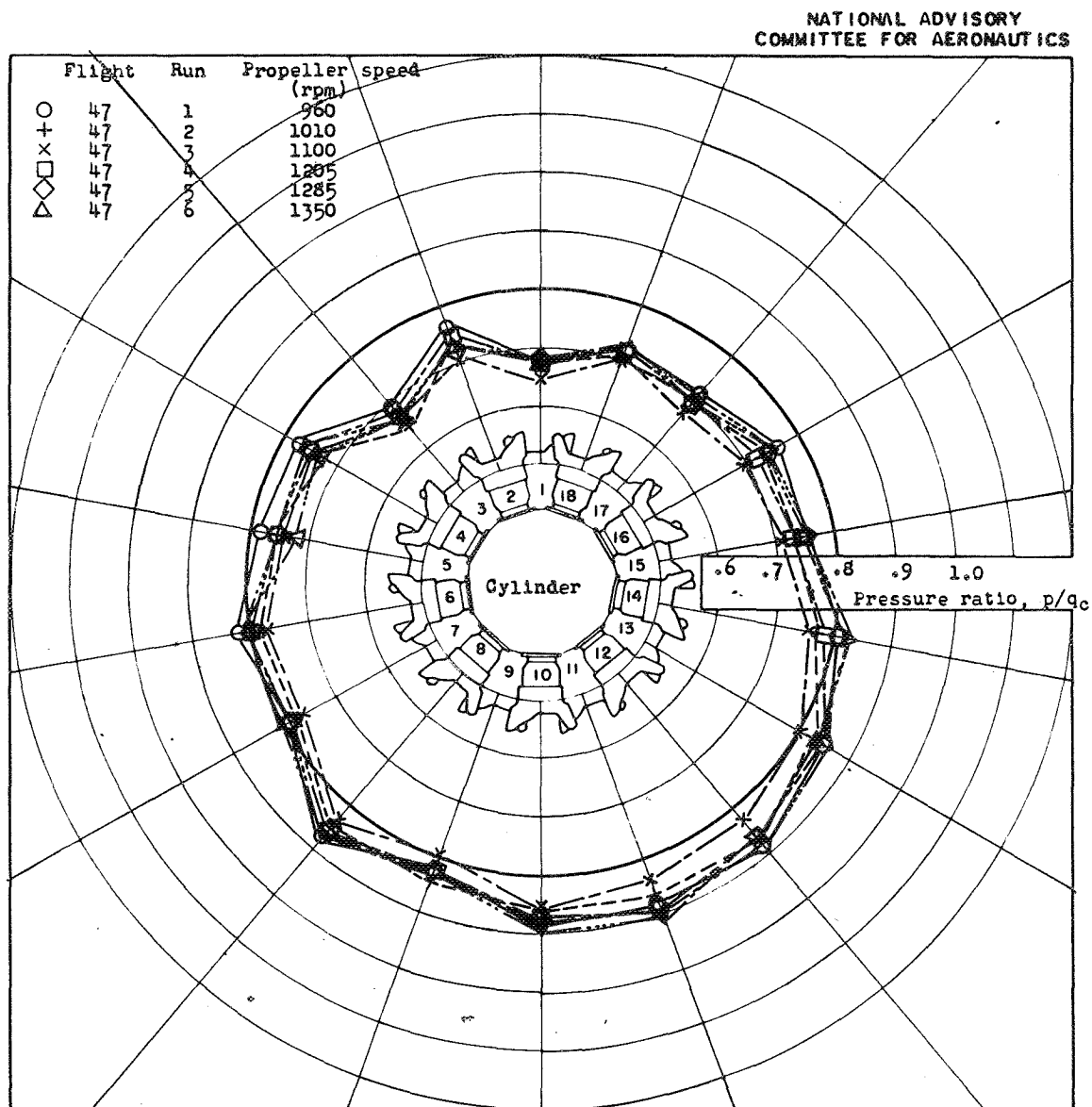
(c) Radial distribution, cylinder 9.

Figure 6. - Continued. Effect of cowl-flap position on cooling-air pressure distribution.



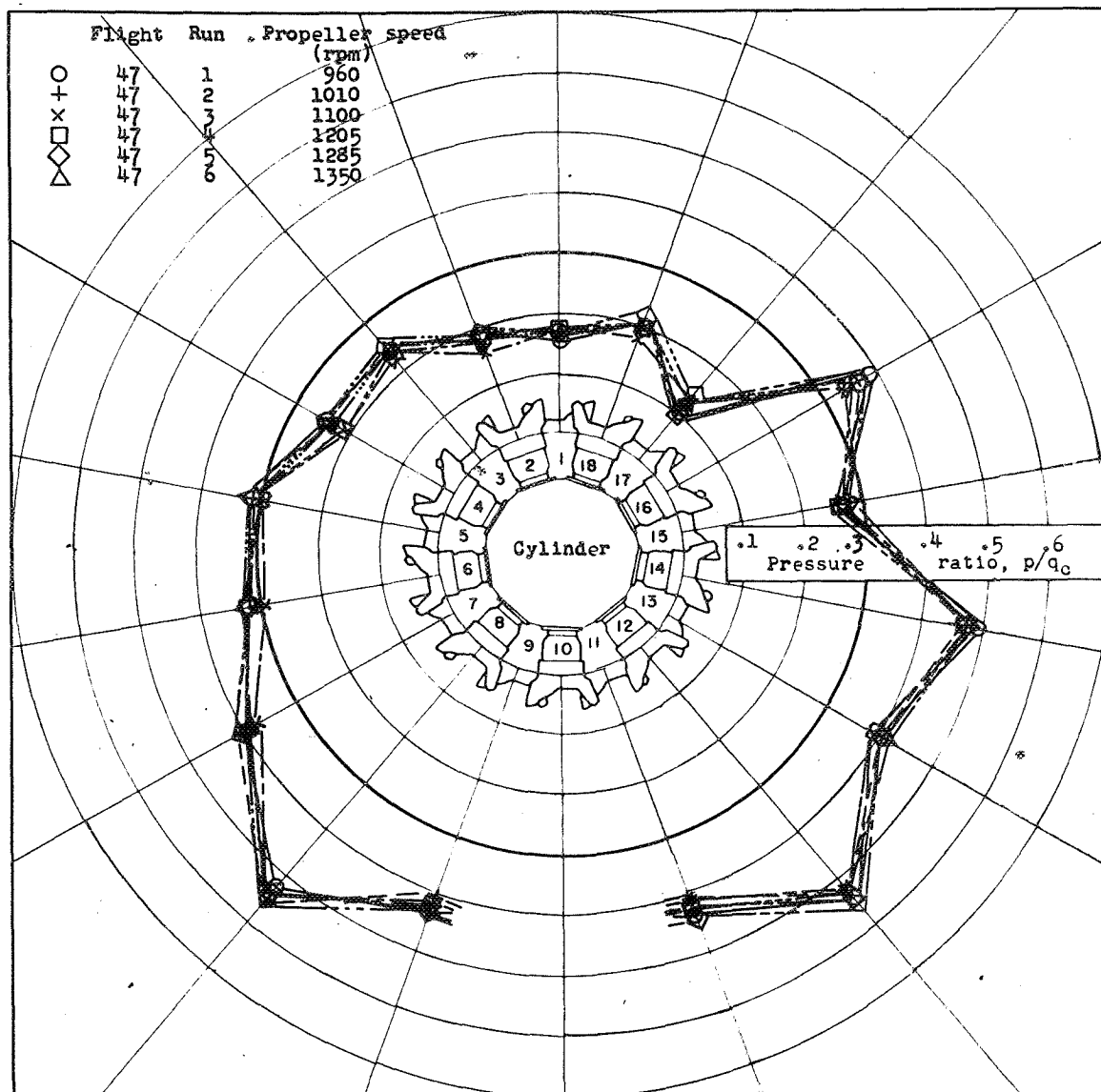
(d) Circumferential distribution of pressure drop across cylinder heads, (H5 - P5).

Figure 6. - Concluded. Effect of cowl-flap position on cooling-air pressure distribution.



(a) Circumferential distribution of total-head pressure in front of cylinders, H5.

Figure 7. - Effect of propeller speed on cooling-air pressure distribution.

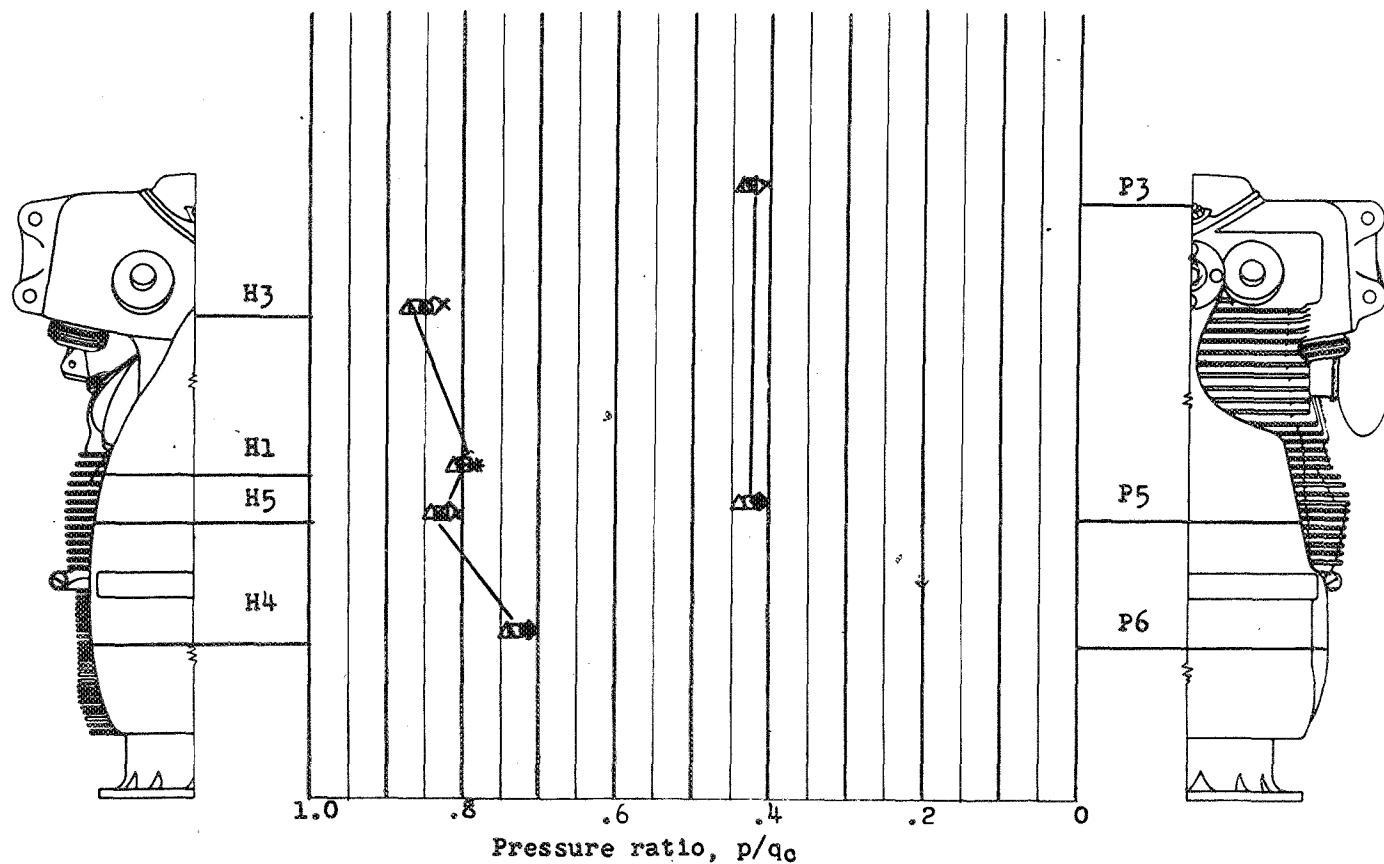
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(b) Circumferential distribution of static pressure at rear of cylinders, P5.

Figure 7. - Continued. Effect of propeller speed on cooling-air pressure distribution.

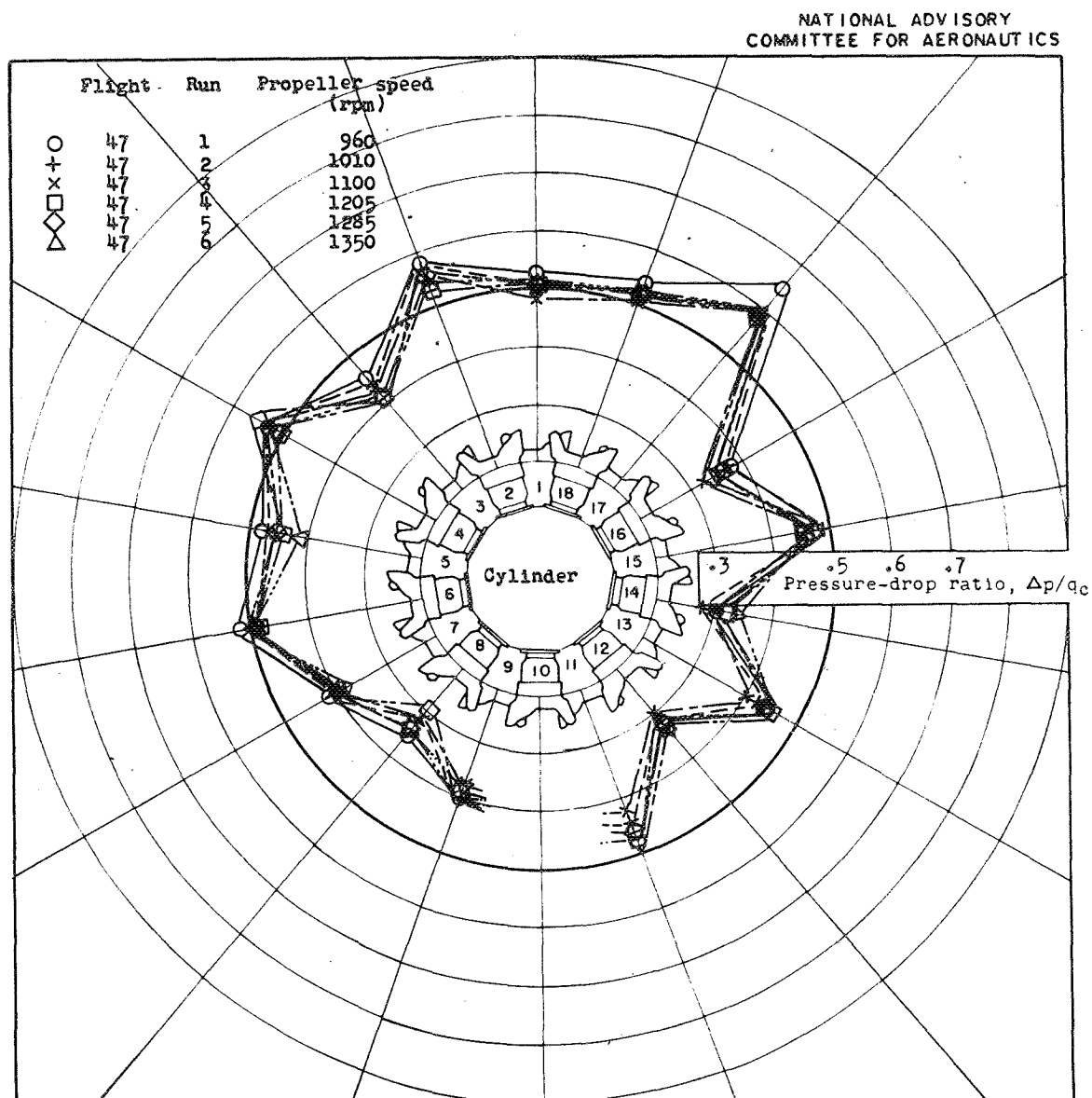
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	Flight	Run	Propeller speed (rpm)
○	47	1	960
+	47	2	1010
x	47	3	1100
□	47	4	1205
◇	47	5	1285
△	47	6	1350



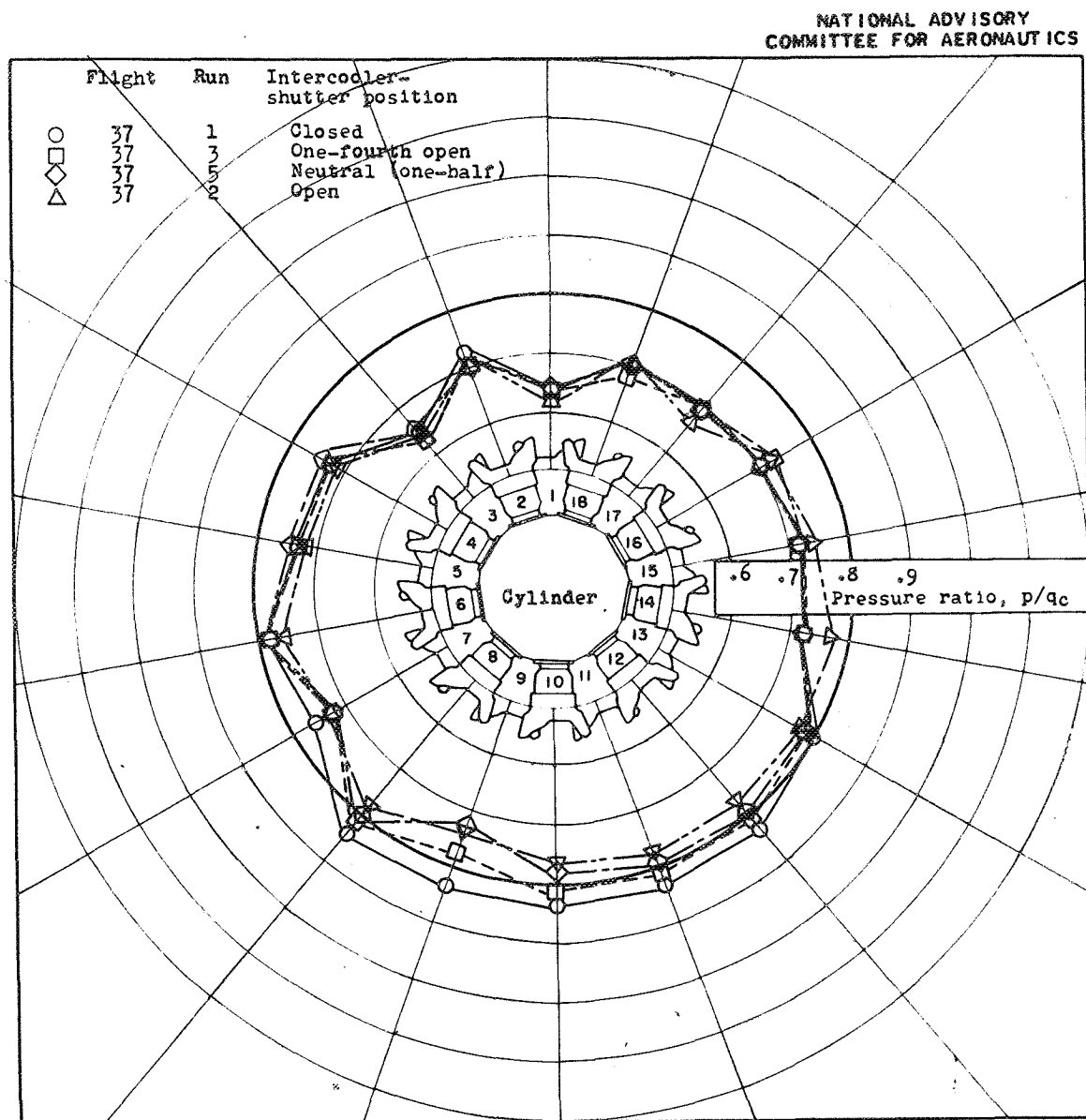
(c) Radial distribution, cylinder 9.

Figure 7. - Continued. Effect of propeller speed on cooling-air pressure distribution.



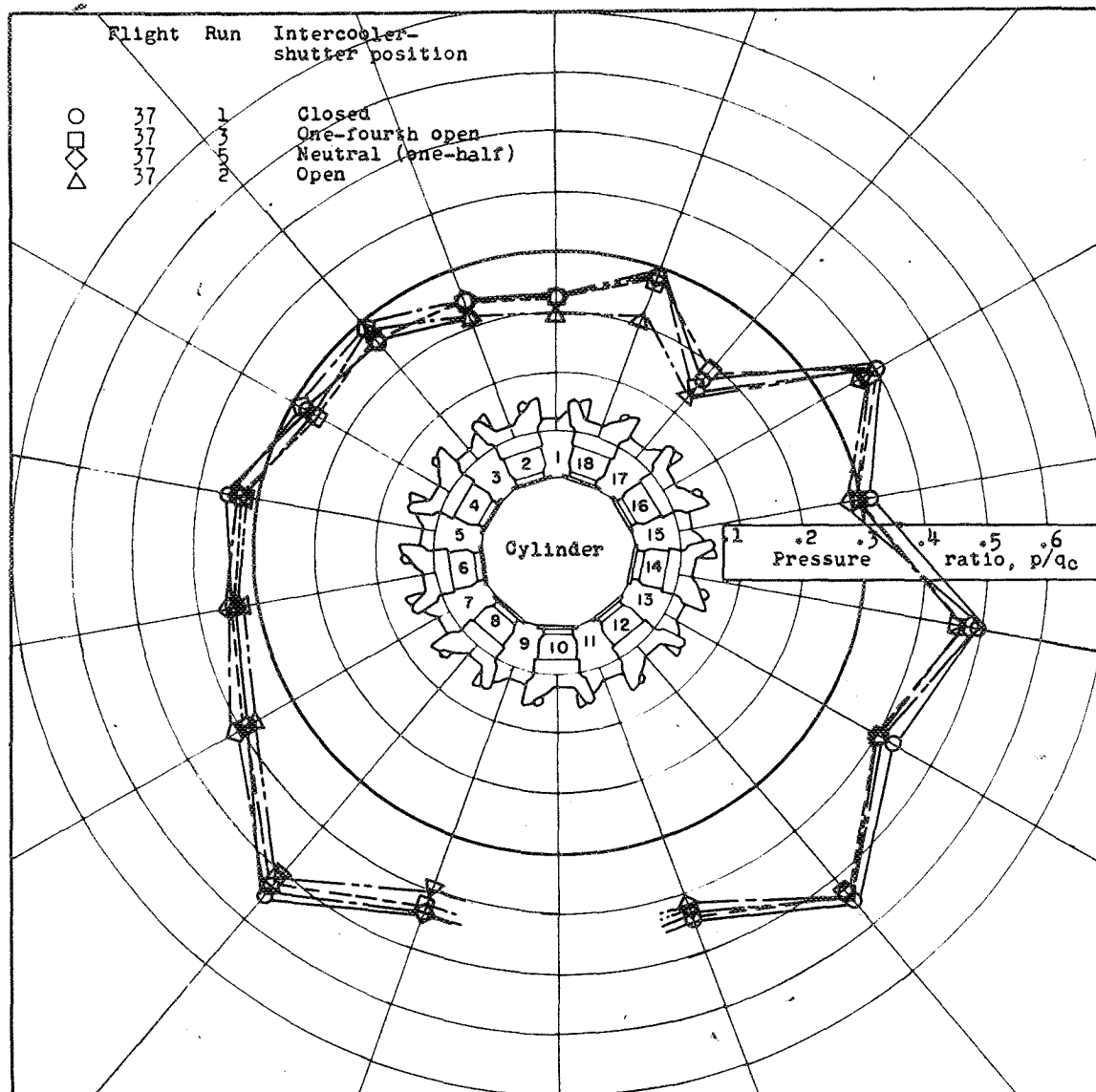
(d) Circumferential distribution of pressure drop across cylinder heads, (H5 - P5).

Figure 7. - Concluded. Effect of propeller speed on cooling-air pressure distribution.



(a) Circumferential distribution of total-head pressure in front of cylinders, H5.

Figure 8. - Effect of auxiliary air flow on cooling-air pressure distribution.

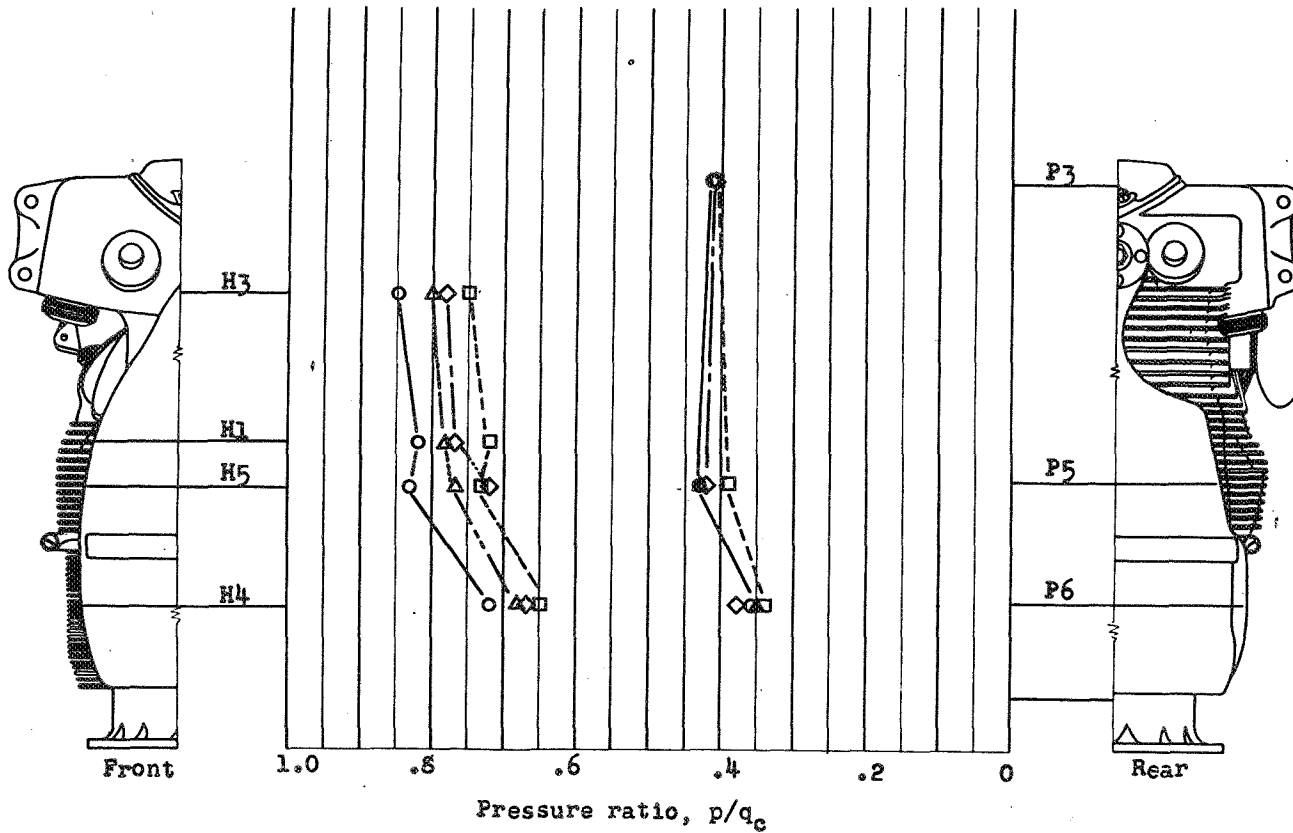
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(b) Circumferential distribution of static pressure at rear of cylinders, P5.

Figure 8. - Continued. Effect of auxiliary air flow on cooling-air pressure distribution.

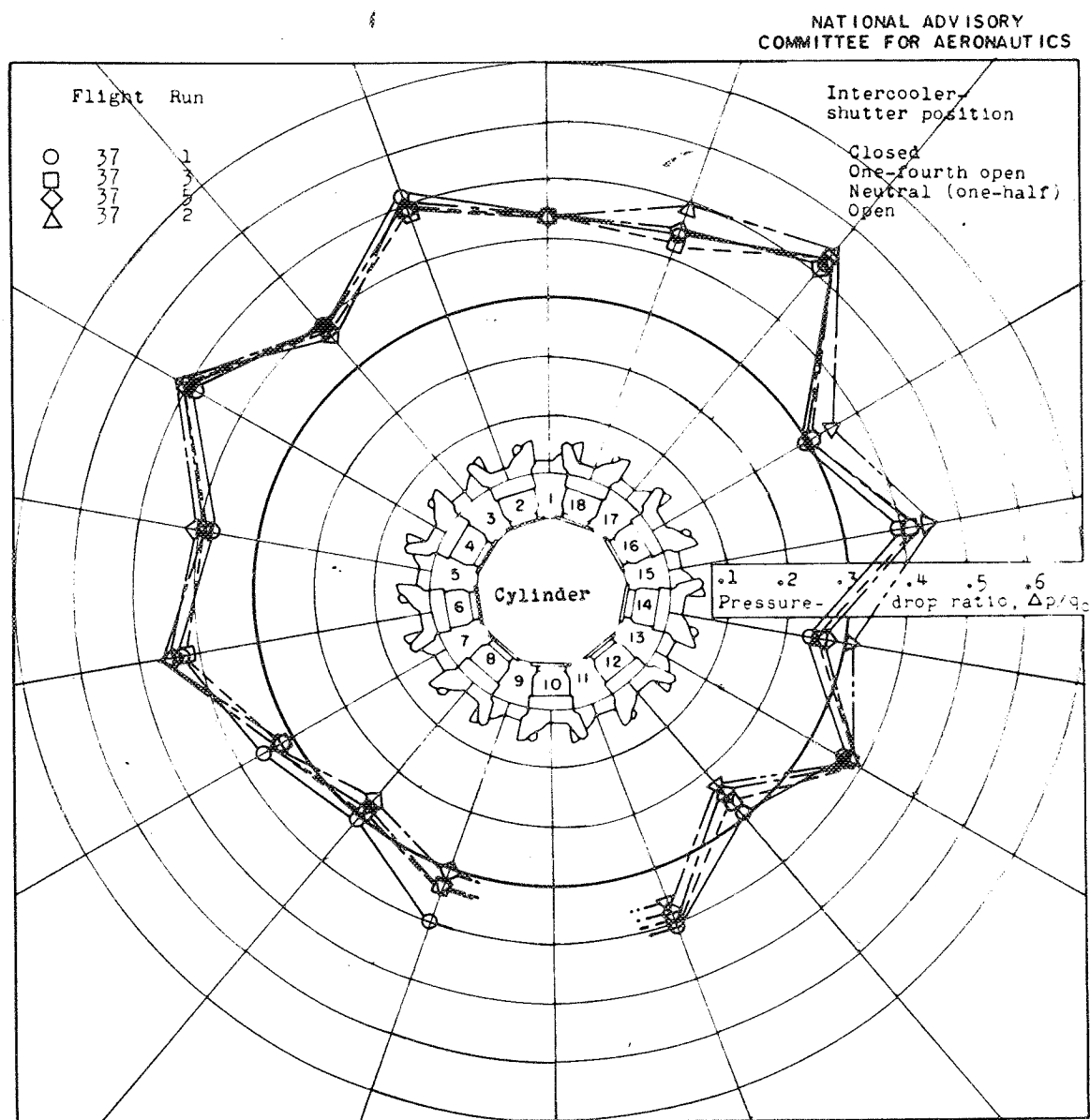
Flight Run Intercooler-
shutter position

○	37	1	Closed
□	37	3	One-fourth open
◇	37	5	Neutral (one-half)
△	37	2	Open



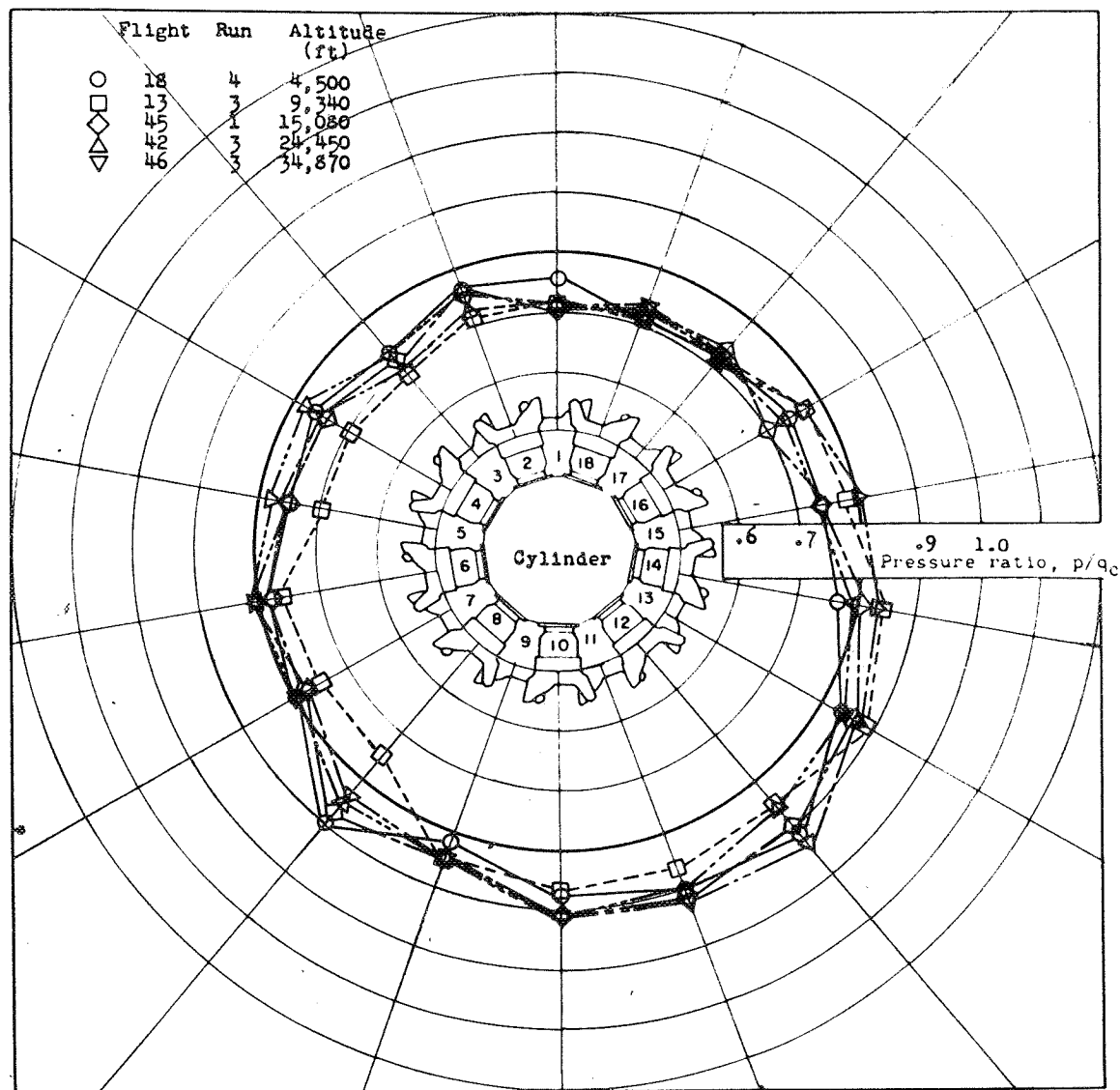
(c) Radial distribution, cylinder 9.

Figure 8. - Continued. Effect of auxiliary air flow on cooling-air pressure distribution.

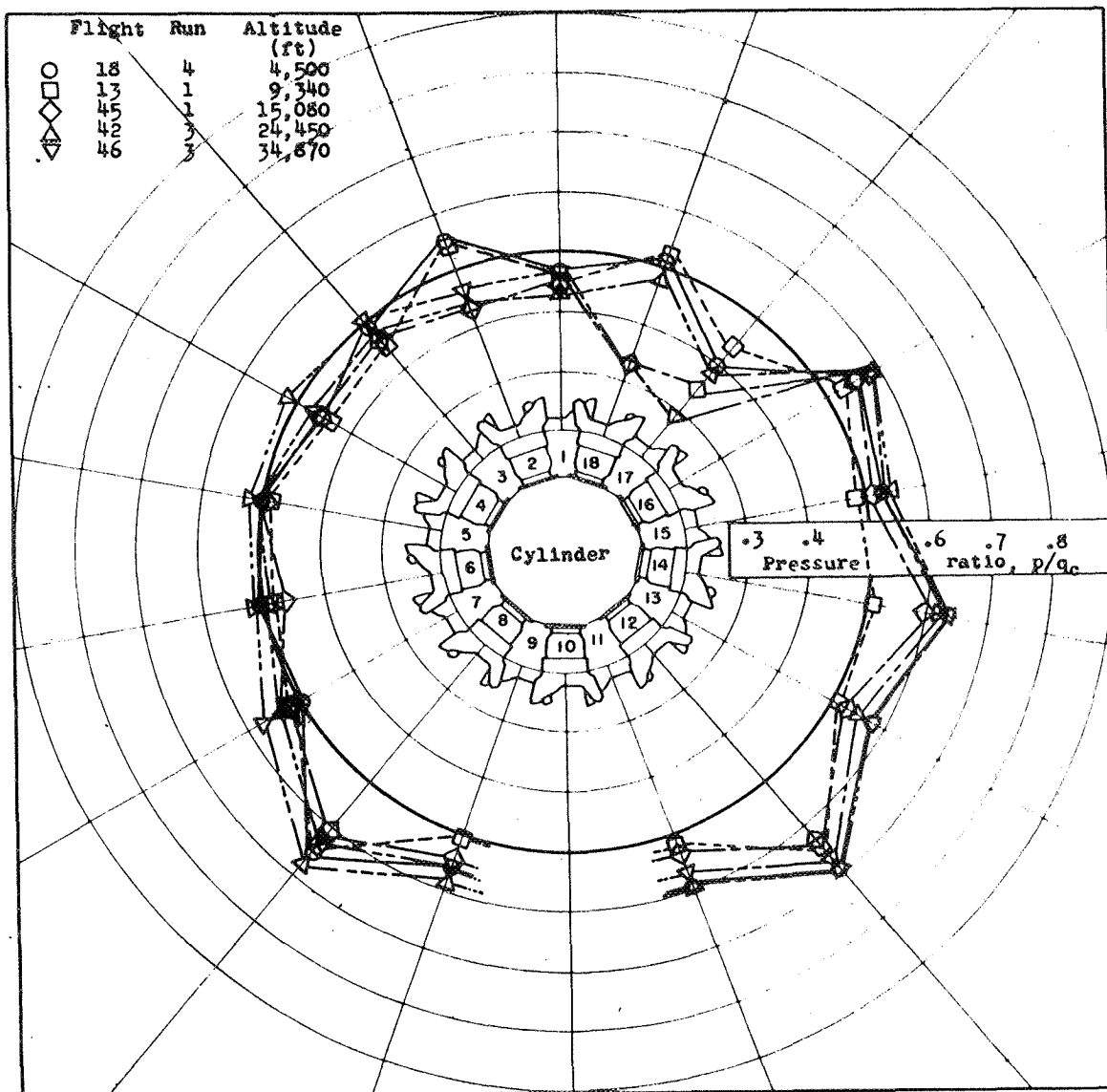


(d) Circumferential distribution of pressure drop across cylinder heads, (H5 - P5).

Figure 8. - Concluded. Effect of auxiliary air flow on cooling-air pressure distribution.

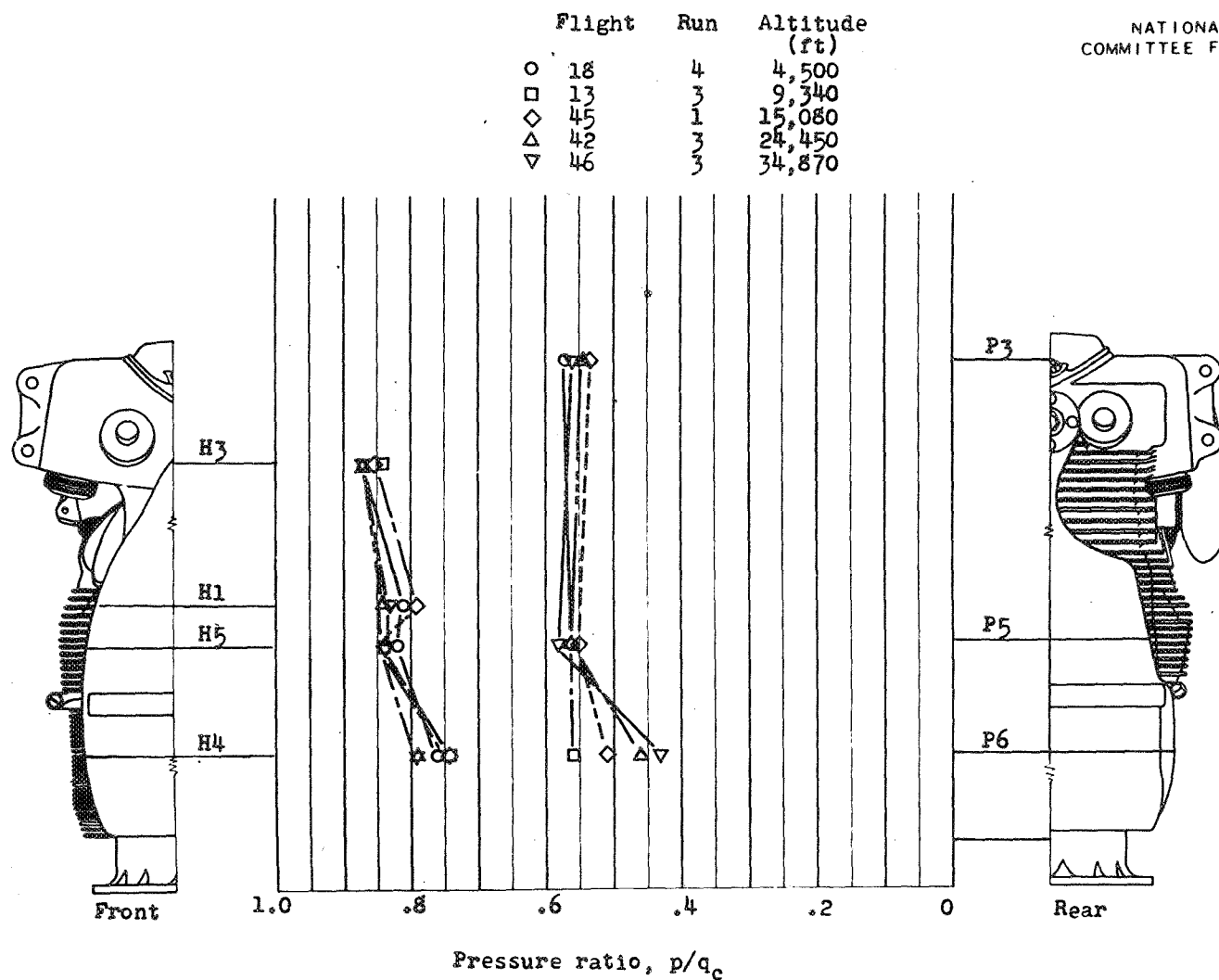
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(a) Circumferential distribution of total-head pressure in front of cylinders, H5.
 Figure 9. - Effect of altitude at constant inclination of the thrust axis on cooling-air pressure distribution.

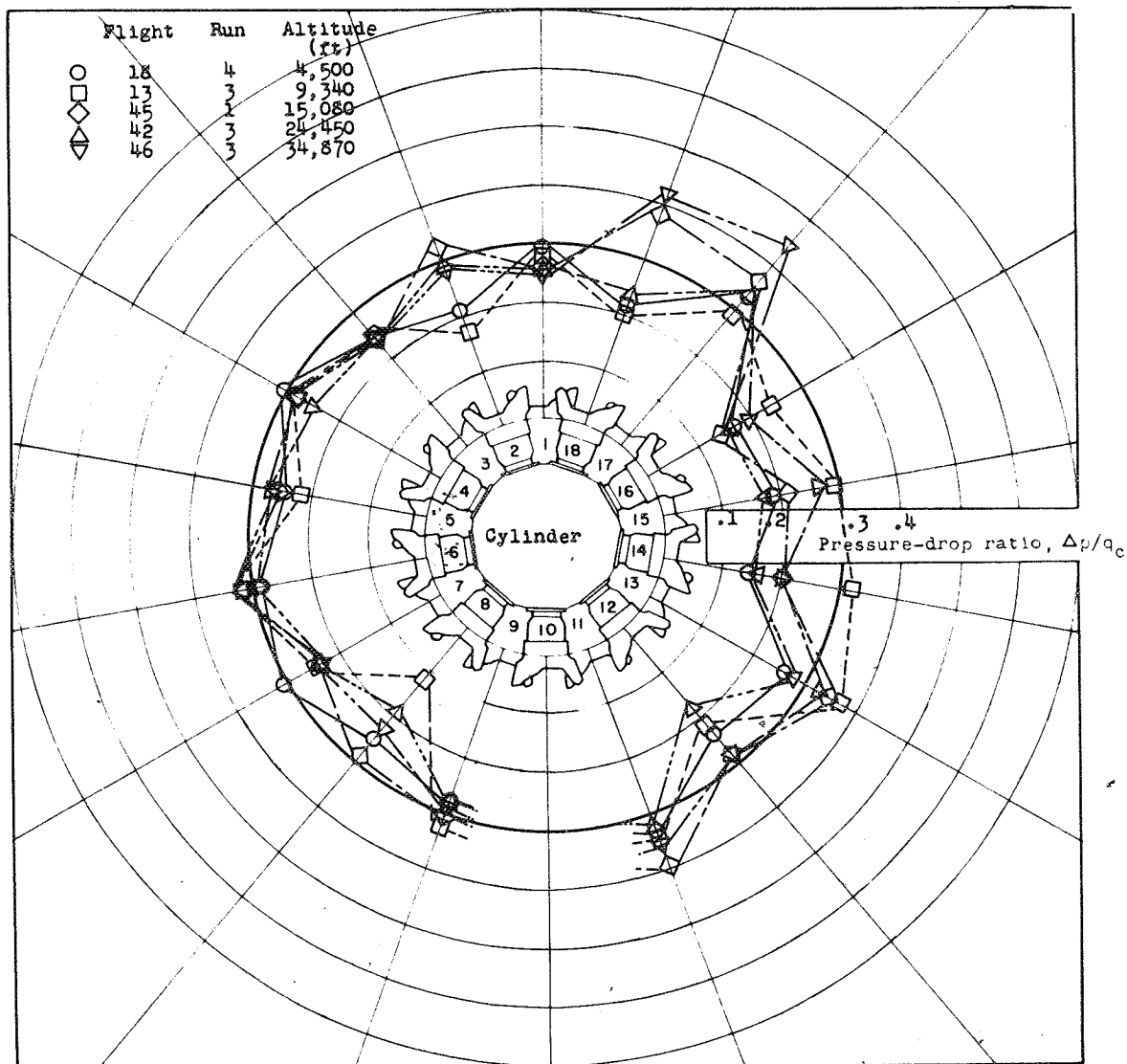
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(b) Circumferential distribution of static pressure at rear of cylinders, P5.

Figure 9. - Continued. Effect of altitude at constant inclination of the thrust axis on cooling-air pressure distribution.

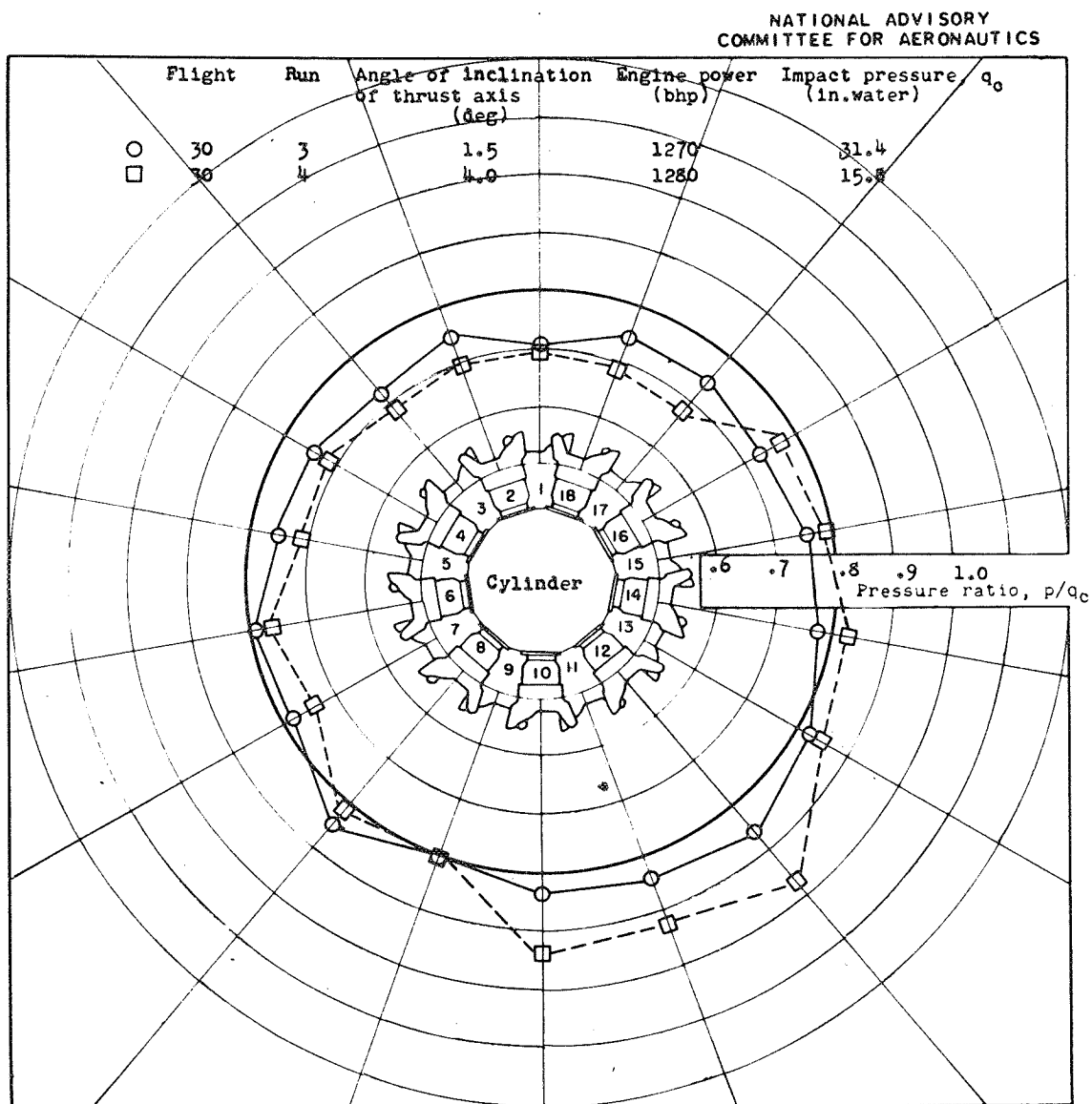


(c) Radial distribution, cylinder 9.
Figure 9. - Continued. Effect of altitude at constant inclination of the thrust axis on cooling-air pressure distribution.

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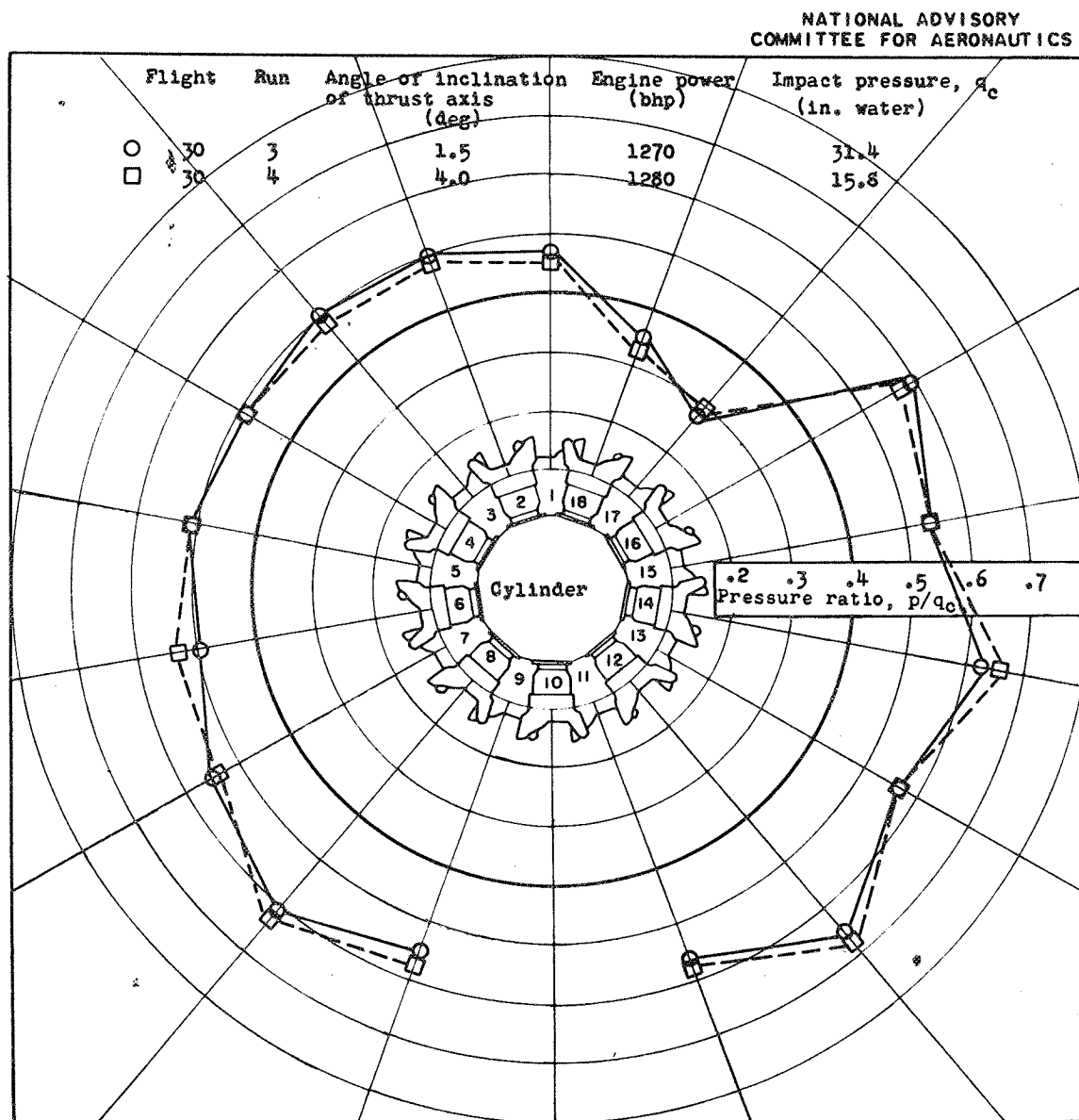
(d) Circumferential distribution of pressure drop across cylinder heads, (H5 - P5).

Figure 9. - Concluded. Effect of altitude at constant inclination of the thrust axis on cooling-air pressure distribution.



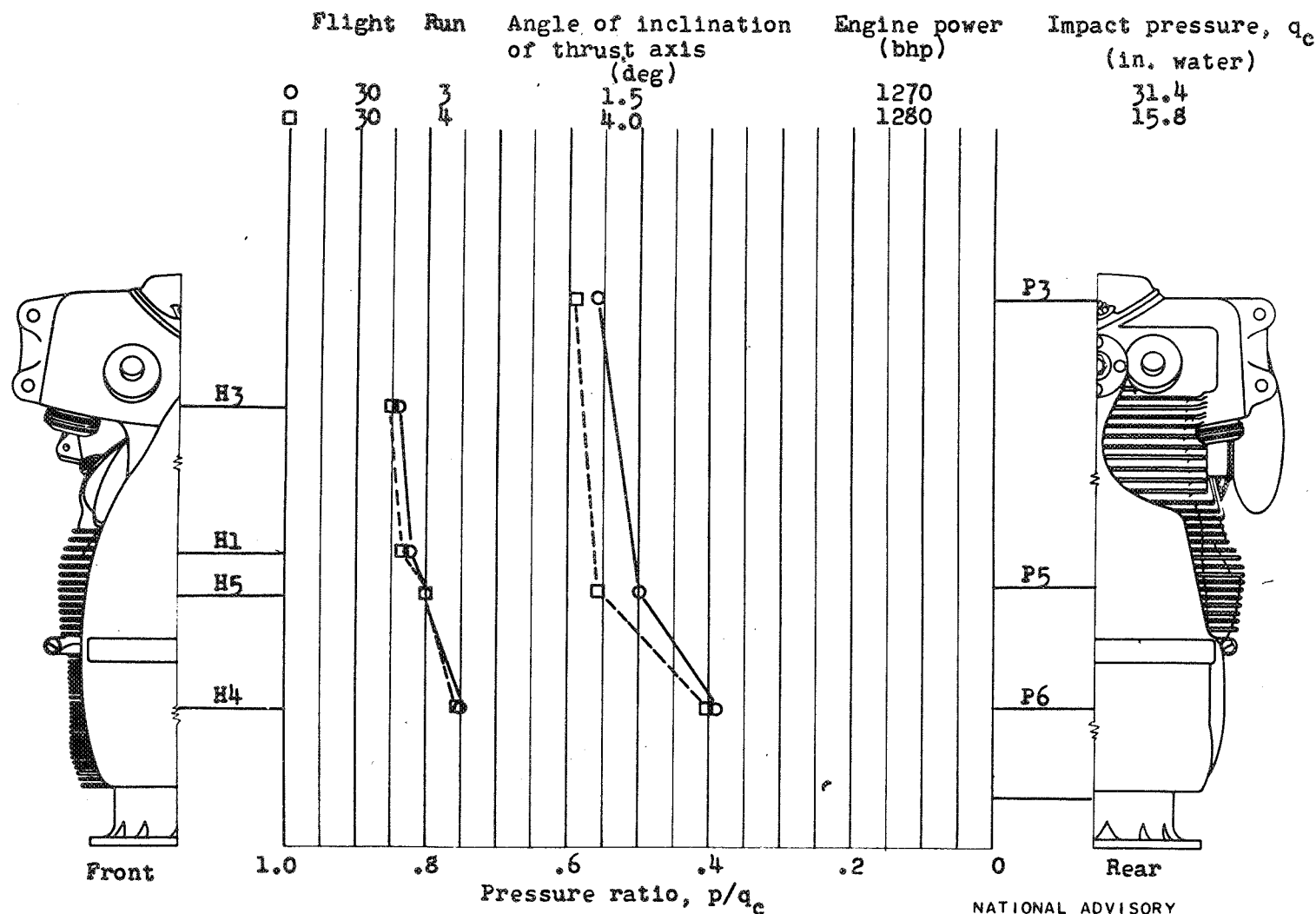
(a) Circumferential distribution of total-head pressure in front of cylinders, H5.

Figure 10.- Effect of angle of inclination of airplane thrust axis at constant engine power on cooling-air pressure distribution.



(b) Circumferential distribution of static pressure at rear of cylinders, P5.

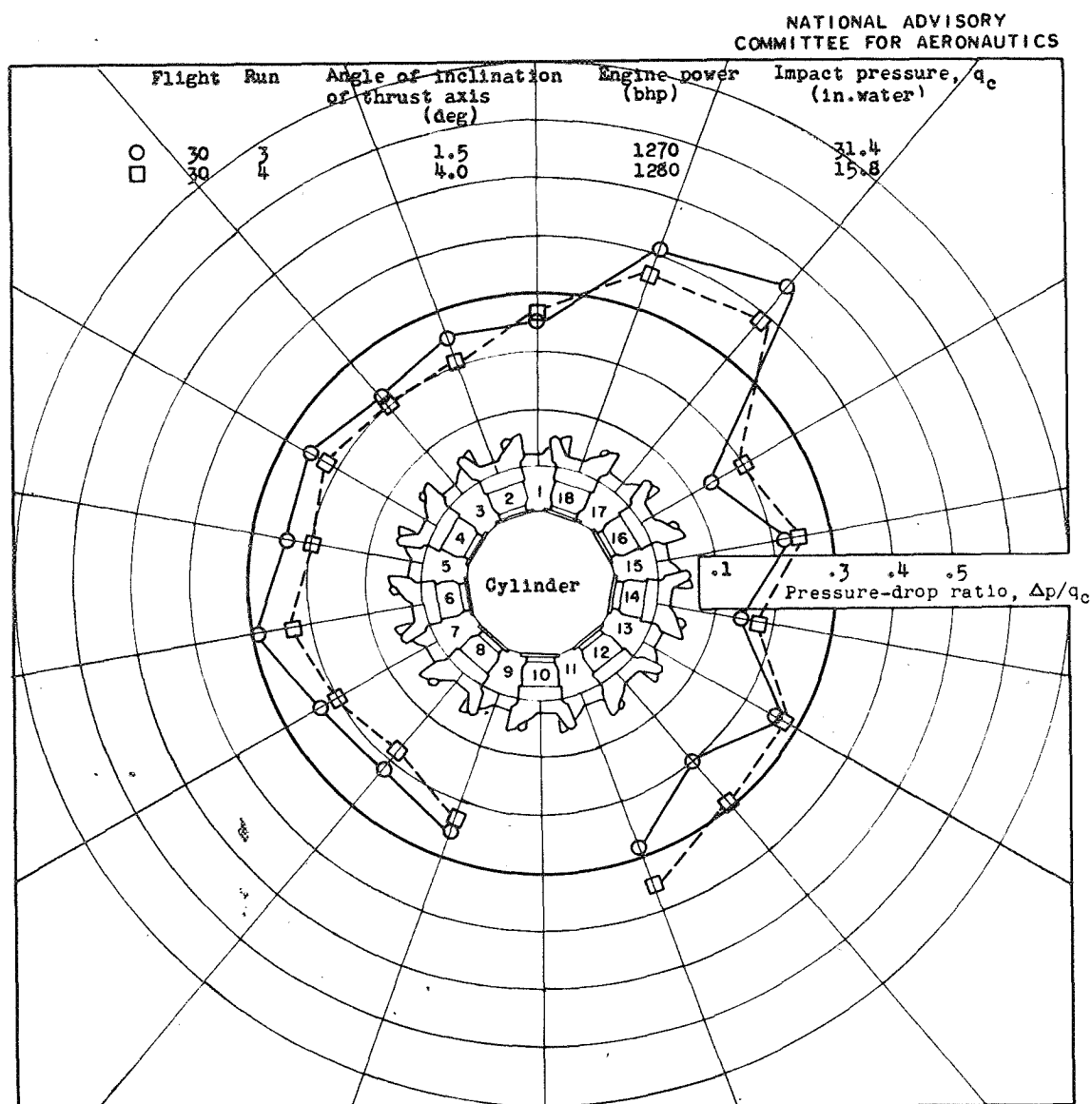
Figure 10. - Continued. Effect of angle of inclination of airplane thrust axis at constant engine power on cooling-air pressure distribution.



(c) Radial distribution, cylinder 9.

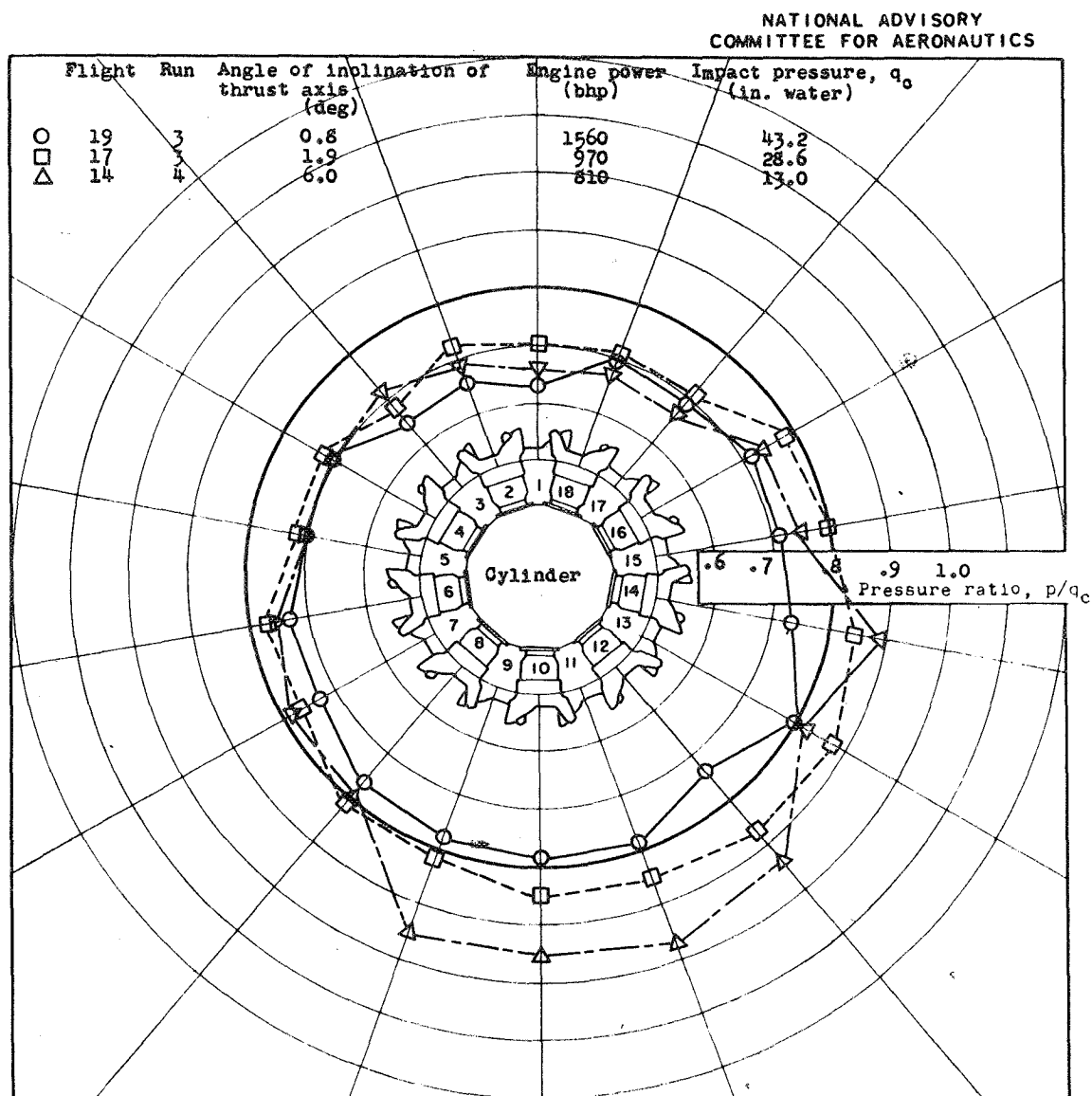
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Figure 10.- Continued. Effect of angle of inclination of airplane thrust axis at constant engine power on cooling-air pressure distribution.



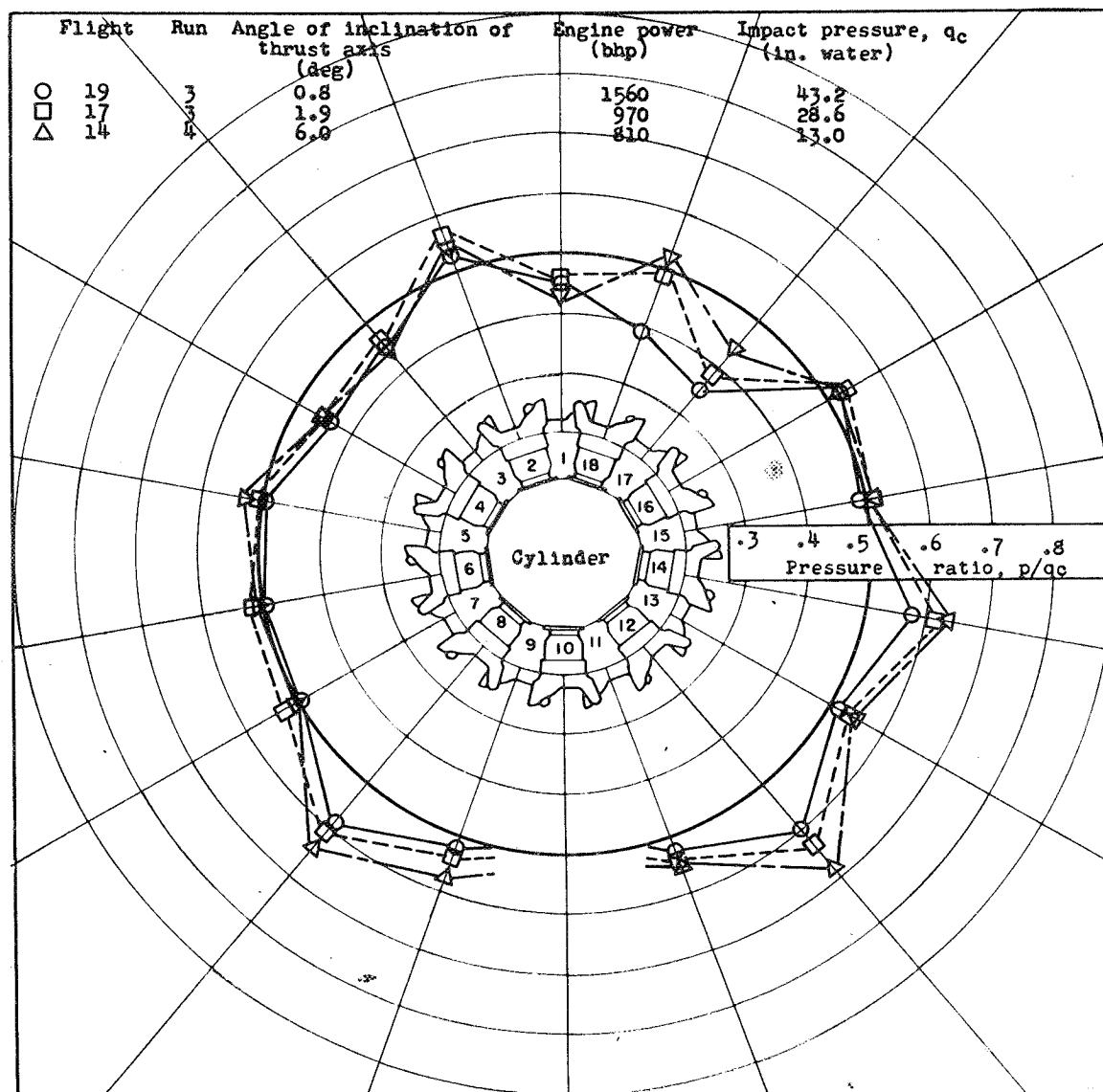
(d) Circumferential distribution of pressure drop across cylinder heads, (H5 - P5).

Figure 10. - Concluded. Effect of angle of inclination of airplane thrust axis at constant engine power on cooling-air pressure distribution.



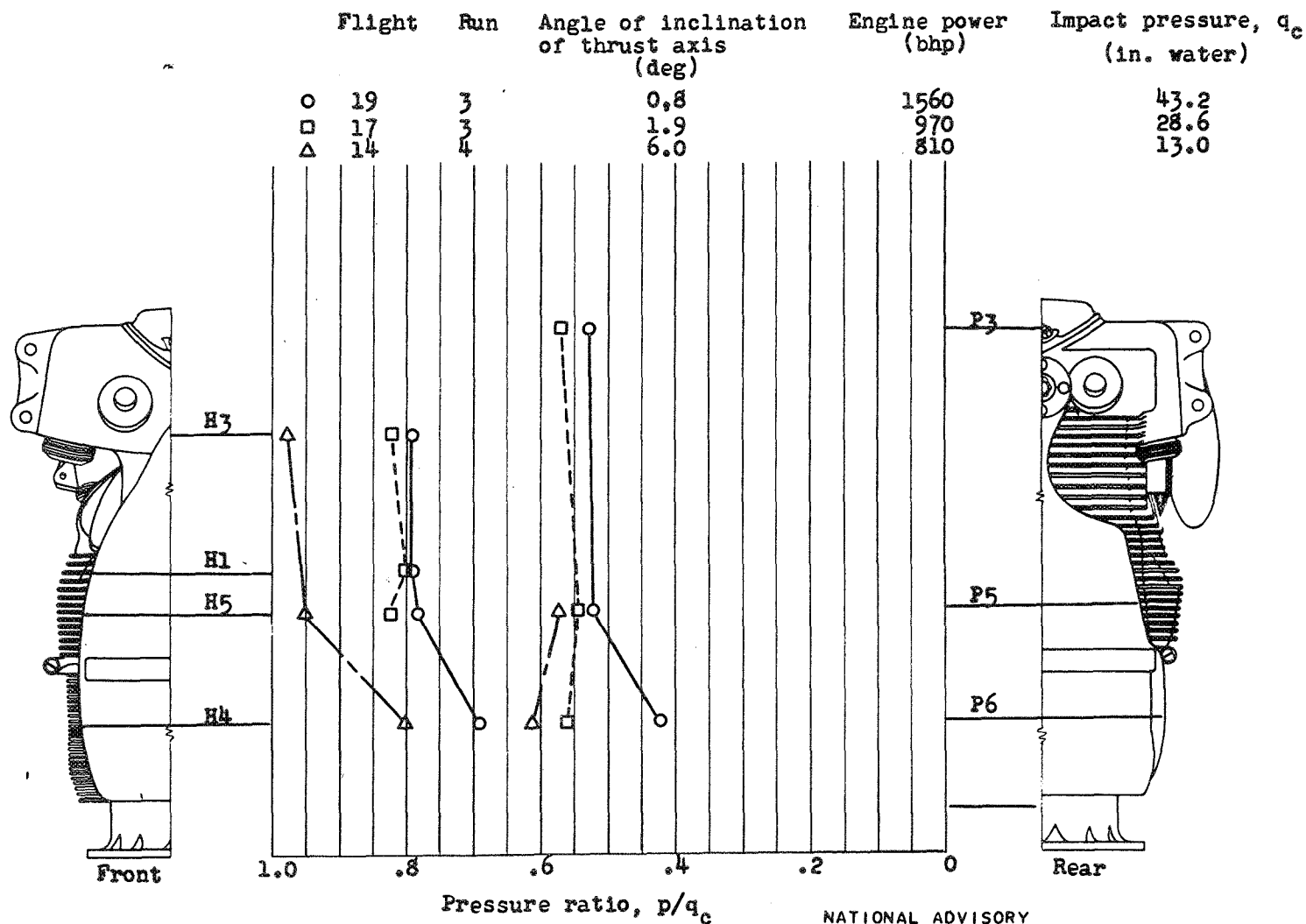
(a) Circumferential distribution of total-head pressure in front of cylinders, H5.

Figure 11. - Effect of angle of inclination of airplane thrust axis at variable engine power on cooling-air pressure distribution.

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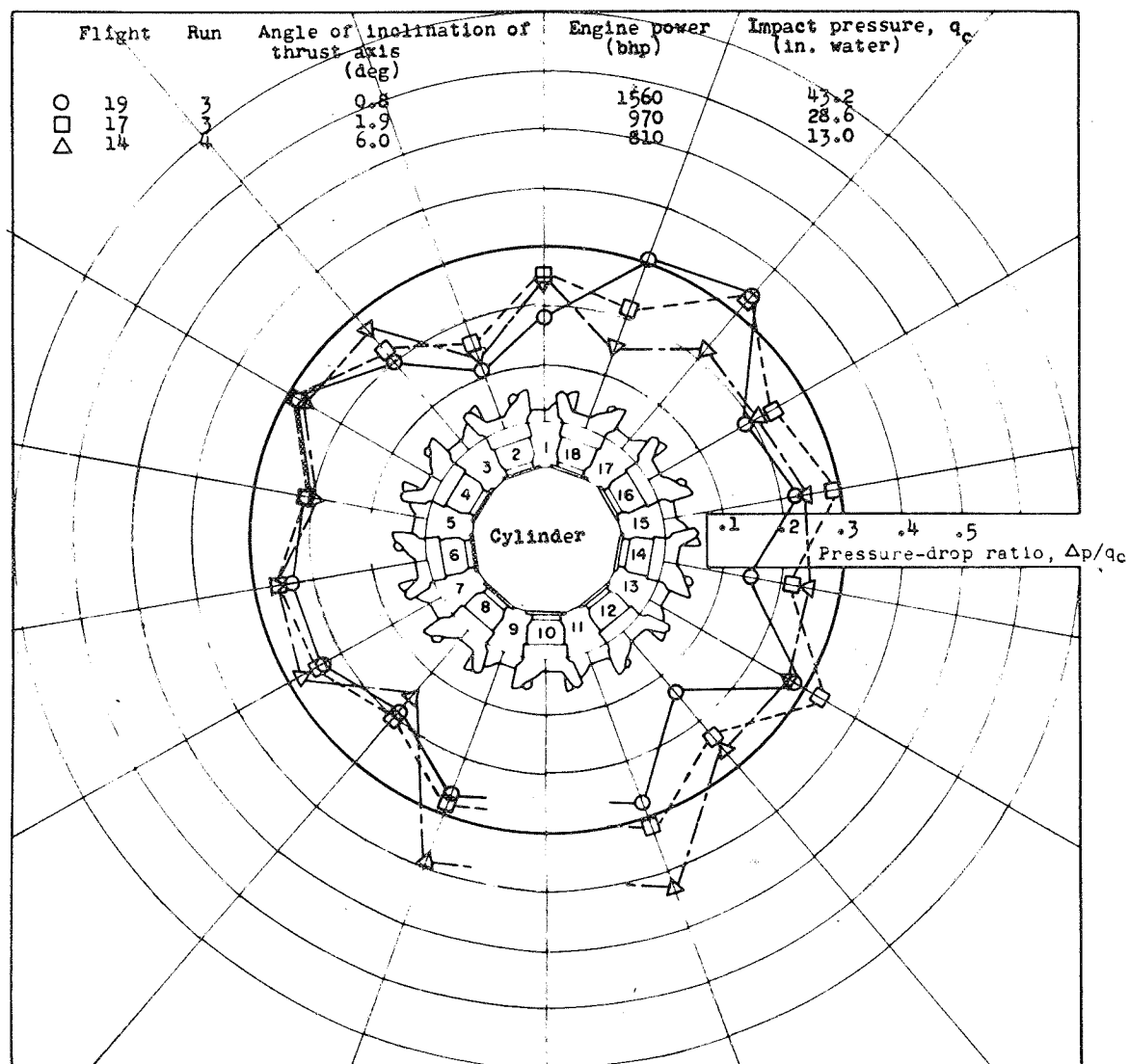
(b) Circumferential distribution of static pressure at rear of cylinders, P5.

Figure 11. - Continued. Effect of angle of inclination of airplane thrust axis at variable engine power on cooling-air pressure distribution.



(c) Radial distribution, cylinder 9.

Figure 11. - Continued. Effect of angle of inclination of airplane thrust axis at variable engine power on cooling-air pressure distribution.

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(d) Circumferential distribution of pressure drop across cylinder heads (H5 - P5).

Figure 11. - Concluded. Effect of angle of inclination of airplane thrust axis at variable engine power on cooling-air pressure distribution.